# GENETIC DIFFERENCES IN ROOT MORPHOLOGY OF BARLEY AND SIGNIFICANCE FOR GROWTH IN COMPACT SOIL

by

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# ABSTRACT OF THESIS

Studies were made to investigate the suitability of cereal species and varieties for use in a direct drilling system and to establish whether there is scope for selecting or breeding barley varieties adapted to compact soil conditions.

Initially field experiments were made to study the ability of contrasting cereal varieties to grow in compact soil (direct drilling) by comparison with their growth and productivity in normally ploughed and cultivated soil. The relative grain yields after direct drilling and ploughing varied between sites and seasons. In some experiments there was evidence of a variety x cultivation interaction; however it was concluded that the results were too inconsistent to identify factors which made a variety adapted to compact soil.

It was concluded, from the literature, that increased soil compaction was one of the main factors limiting crop growth after direct drilling. Studies were made to establish whether there is scope for selecting or breeding barley varieties with root systems adapted to compact soil conditions. The first step was to establish the range of variation in root system characters among barley varieties. To facilitate the study of varieties with a wide range of phenotypes all subsequent studies were made in the laboratory or glasshouse.

A survey was made of the seedling root characters of 96 barley varieties, which had been selected to have as diverse a geographical and/or genetic origin as possible. Measurements of seminal root number, length and diameter among varieties indicated that expression of these characters were mainly controlled by additive polygenic systems. An estimate of the broad sense heritability of root characters was made from a study of 10 selected varieties. This and other evidence indicated that seedling root number was the most strongly inherited root character, followed in decreasing order by total root length, mean seminal root length and root diameter.

In 1978 experiments were made in which barley varieties were grown in soil artificially compacted to varying bulk densities. Varieties with diverse seminal root numbers and diameters were selected for these experiments from the varieties previously surveyed.

In general seedling root length decreased and root diameter increased with increasing soil compaction. Varietal differences in seminal number and diameter did not affect their response to soil compaction. Certain varieties had more vigorous root systems than others and consistently produced relatively greater root lengths. It was suggested that such varieties would be better able to meet the plant requirements for nutrients in compact soil. The artificially compacted soil used in these experiments lacked the cracks and continuous pores characteristic of many field soils compacted under direct drilling. It was argued that in a compacted field soil a variety with many seminal roots would have a greater chance of one or more roots encountering the cracks along which roots can grow and proliferate sufficiently to meet the needs of the developing plant.

## DECLARATION

I declare that I have composed this thesis myself. The work embodied in it is the result of my own investigations except where reference has been made to published literature.

P.L. Bragg

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# PART I

# FIELD EXPERIMENTS

## SECTION 1

## REVIEW: DIRECT DRILLING, SOIL CONDITIONS AND CROP GROWTH

# 1. REVIEW: DIRECT DRILLING, SOIL CONDITIONS AND CROP GROWTH

## 1.1 The History of Direct Drilling

The physical condition of soil untouched by agriculture is usually better than that in our arable fields (Pereira 1975). So why do we till the land? In the first half of this century two schools of thought existed as to the function of tillage. The German school believed the main function of tillage was to alter the physical condition of the soil (Kuipers 1970). The English school led by E.W. Russell believed that the main importance of tillage was as a method of weed control (Russell and Keen 1938).

Early studies of the effects of minimum cultivation on soil conditions were hampered because the available herbicides remained active, either in the soil or on plant debris, long after application. Two decades ago the introduction of the bipyridyl herbicides, in particular paraquat (the 1,1,-dimethyl-4, 4,-bipyridilium ion), overcame this problem and gave the opportunity to study minimum cultivation (Allen 1975). Paraquat has three important properties:-

1. It kills green vegetation and is particularly effective on many grasses.
2. It is absorbed quickly into sprayed foliage.
3. It is inactivated immediately on contact with most soils.

The technique of minimum cultivation using herbicides to replace the action of tillage as a method of weed control was labelled direct drilling by Hood, Jameson and Cotterell (1963). A number of other terms such as zero or no-tillage, direct or sod seeding and stubble planting have also been used to describe husbandry systems similar to that defined above.

Direct drilling was seen as an important new technique for a number of reasons (Kuipers 1970; MAFF 1970); it has a low labour requirement and so gives an opportunity for timeliness of operations and allows a greater area to be covered at peak autumn and spring periods. There is also less risk of damage to soil structure in difficult seasons. Organic residues are concentrated at the soil surface giving a good soil structure where it is most useful; these residues also help to prevent blowing on light land. In the absence of cultivation weed seeds are not brought to the soil surface.

Despite the advantages discussed above the adoption of direct drilling has not been as widespread as was originally expected and several problems have been found to be associated with the technique. Perennial grass weeds particularly couch (Agropyron repens) are difficult to control with paraquat, although the recently introduced herbicide glyphosate is more successful in this respect. Initial problems with direct drill machinery were also experienced. Early direct drills left an open drill slit which exposed the grain to predation by birds and slugs. On certain soils reduced water infiltration after direct drilling may lead to surface wetness with deleterious effects on crop growth. The effects of direct drilling on soil conditions are discussed more fully in Section 1.2.

Crop residues left on the soil surface under direct drilling may carry inoculum of diseases such as eyespot (Pseudocercosporella herpotrichoides) and leaf and glume blotch of wheat (Rhynochosporium secalis and Pyrenophera teres). Straw burning may help to reduce the incidence of foliar diseases after direct drilling although high levels of infection by R. secalis (Cannell and Ellis 1972) and Septoria spp. are still frequently found (Yarham 1975). These persistant diseases may require fungicidal control to achieve maximum yields after direct drilling, although Yarham (1975) concluded that in general it was unlikely that success or failure with direct drilling was much influenced by cultivation/disease interactions.

Until recently experiments had indicated that lower yields were more likely after direct drilling than after conventional cultivation (Allen 1975, Davidson and Santelman 1973; Davies and Cannell 1975). As knowledge and experience of direct drilling have increased, so results have improved and in certain circumstances yields similar to those found after conventional cultivation can be achieved (Davies and Cannell 1975). Bakermans and de Wit (1970) concluded that in Holland, except on soils with a panning subsoil, cereals gave similar yields under both direct drilling and conventional cultivation. In Britain Cannell et al (1978) have empirically classified soils for their suitability for the use of direct drilling. They concluded that on 30% of the cereal growing area, soil conditions are such that direct drilling may be expected to produce similar yields for both autumn and spring sown crops. On other soils, they concluded, direct drilling may not always produce adequate yields and the reasons for this must be evaluated before direct drilling can be more fully exploited.

With the introduction of new herbicides and improved management techniques many of the early problems of direct drilling have been overcome. Attention has become particularly focused on the effect on root growth of the soil conditions produced by direct drilling to identify the soil factors limiting crop growth.

## 1.2 Direct Drilling and Soil Conditions

The effect of direct drilling on soil conditions is governed by a complex interaction of several factors, notably soil type, previous history and weather both before and after drilling. However the practice of direct drilling almost invariably produces soil conditions markedly different from those found after conventional cultivation. In the following discussion the effects of direct drilling on soil conditions are assessed by comparison with soil conditions under conventional cultivation.

### 1.2.1 Compaction

After direct drilling soil is usually more compact with increased bulk density particularly near the soil surface. Pidgeon and Soane (1977) studied the effects of direct drilling on soil properties on a long-term field experiment growing continuous spring barley near Edinburgh. They found that bulk density was greater under direct drilling from 0-18 cm, although below the depth of normal ploughing (15-20 cm) there were no differences in bulk density between the normal ploughed and direct drilled treatments. Cannell and Finney (1973) and Baeumer and Bakermans (1973) reported similar effects on soil conditions in their reviews of experiments comparing direct drilling with conventional cultivation in Europe and the USA.

The increased soil bulk density under direct drilling is usually accompanied by an increase in mechanical strength as estimated by penetrometer resistance (Cannell and Finney 1973; Baeumer and Bakermans 1973; Ellis, Elliott, Barnes and Howse 1977; Pidgeon and Soane 1977). Although this increase in mechanical strength may not be found on certain light soils or on soils with a high organic matter content (Jones, Moody and Lillard 1969; van Ouwerkerk and Boone 1970; Bachthaler 1971). The increase in soil mechanical strength may improve the bearing capacity of untilled soil and thus have beneficial effects on trafficability (Soane, Butson and Pidgeon 1975).

1.2.2 Porosity

As the soil bulk density is increased under direct drilling there is a concomitant decrease in soil pore space which in field and laboratory studies has been found to be particularly due to a reduction in the proportion of large pores (van Ouwerkerk and Boone 1970; Baeumer, Ehlers and Pape 1971; Cannell and Finney 1973; El-Karouri 1974). These larger pores, greater than 30-60 μm in diameter, have an important function in soil as water drains from them under gravity whereas it is held by capillary forces in smaller pores (E.W. Russell 1973, p.479). Thus any decrease in the proportion of large pores under direct drilling may impair aeration and drainage especially on heavy clay soils in high rainfall areas.

1.2.3 Moisture

In many field experiments on different soil types soil moisture contents have been greater under direct drilling than conventional cultivation, particularly near the soil surface (van Ouwerkerk and Boone 1970; Baeumer and Bakermans 1973; Finney and Knight 1973; Soane and Pidgeon 1974; Ellis, Elliott, Barnes and Howes 1977). The increase in soil moisture under direct drilling has been attributed to a variety of causes. Soane and Pidgeon (1974) suggested that it could be due to reduced evaporation because of the mulching effect of unburnt stubble and reduced surface roughness. An alternative hypothesis is suggested by the results of Archer and Smith (1972). In laboratory experiments they found that increased soil bulk density resulted in an increase in soil moisture content at a given soil water potential. The increase in soil moisture content occurred despite a reduction in total pore space and Archer and Smith (1972) suggested that in compact soil there was a larger fraction of small soil pores which would store soil water.

The infiltration of rain to depth may be greater in untilled than in conventionally cultivated soil (Baeumer and Bakermans 1973; Goss, Howse and Harris 1978). This increased infiltration has been attributed to the following changes in soil properties:-

1. Planes of weakness, formed between structural units by the shrinking of soil or made by roots of previous crops, can persist longer when soil is undisturbed (Russell, Cannell and Goss 1975).
2. A greater earthworm population is often found in direct drilled soil (Holmes 1976; Ellis, Elliott, Barnes and Howse 1977) and these may produce abundant large vertical channels down which water can rapidly percolate (Ehlers 1975; Goss, Howse and Harris 1978).

The relative importance of these different factors in increasing infiltration may be expected to vary depending on soil type and local climate. In fine-textured and unstable soils, infiltration of water through the surface soil may be slower after direct drilling and ponding may result if rainfall is high and evapotranspiration is low (Russell, Cannell and Goss 1975).

#### 1.2.4 Aeration

There is little information on the effects of tillage on soil aeration, although it might be expected that aeration would be more restricted in soil under direct drilling than under conventional cultivation due to the higher bulk density and the lower volume of large drainable pores (see Sections 1.2.1 and 1.2.2). In experiments made in Holland on a range of soil types, it was reported that there were more regions of low air content in soil on direct drilled plots than on ploughed plots (van Ouwerkerk and Boone 1970). However in experiments made in England on a clay soil higher oxygen concentrations were found in soil during the winter after direct drilling than after conventional cultivation (Dowdell, Crees, Burford and Cannell 1979); it was suggested that this was due to development of more continuous large pores and channels under direct drilling.

1.2.5 Organic Matter and Stability of Aggregates

With direct drilling plant residues are left on the soil surface and in temperate climates the quantity of organic matter in the surface layers may increase after several years (Bakermans and de Wit 1970; Cannell and Finney 1973; Ellis, Elliott, Barnes and Howse 1977). This can have a beneficial effect on soil structure as additional organic matter in soil tends to reduce the effect of compacting forces and to enhance recovery of an open structure in compacted soils (Cannell, Davies, Mackney and Pidgeon 1978). The increase in organic matter may be associated with an increase in the stability of aggregates in the surface layers of direct drilled soil relative to that in conventionally cultivated soil (Douglas 1977). This result is not unexpected as there is much evidence that organic substances can influence the stability of soil aggregates, thus creating and preserving the porous structure of the soil (Russell 1971).

1.2.6 Nutrients and pH

The lack of soil disturbance under direct drilling can lead to an increase in the concentration of slowly diffusing nutrients such as potassium and phosphorus in the surface soil layers (Hodgson, Proud and Browne 1977; Ellis, Elliott, Barnes and Howse 1977). Although the effect of direct drilling on soil pH has not be extensively studied there is some evidence that the pH of the surface soil layers may be lower under direct drilling than conventional cultivation (Shear and Moschler 1969; Hodgson, Proud and Browne 1977; Ellis, Elliott, Barnes and Howse 1977).

It has often been found that direct drilled crops require higher fertiliser nitrogen application to produce equivalent yields to those produced under conventional cultivation (Bakermans and de Wit 1970; Holmes 1976). A number of explanations for this have been suggested; these include lower plant populations (Bakermans and de Wit 1970), greater weed competition (Baeumer 1970) and restricted root development (Holmes 1976) under minimum cultivation. An additional explanation has been suggested by Dowdell and Cannell (1975) who found that the concentration of nitrate in the soil solution of direct drilled land can be less than on ploughed land; they concluded that this was due to decreased mineralisation of nitrogen in direct drilled soil.

## 1.3 Direct Drilling and Crop Growth

From the review in the previous section it can be seen that the adoption of direct drilling can produce soil conditions which are markedly different from those found under normal cultivation. The changed soil conditions found under direct drilling can have both beneficial and detrimental effects on crop establishment and growth, depending on site and season.

### 1.3.1 Crop Establishment

The emergence of crops established under direct drilling has frequently been found to be poorer than that of crops established under conventional cultivation (Whybrew 1968; Rosenberg 1964; Cannell 1975). The precise cause of the poorer emergence under direct drilling may depend on soil type and soil conditions at drilling. Early direct drills tended, if used in certain soil conditions, to produce smeared drill slits. Although seed germination is normal, further plant growth may be restricted as, in the absence of an overburden on the seed, the mechanical impedance of smeared soil of the slit may be such that roots are unable to penetrate the soil and so the seed may be pushed out of the ground as the seedling roots extend (Prebble 1970). More recently manufactured direct drills which disturb the soil and cover the seed have largely overcome this problem.

The presence of straw residues at drilling has also been found to be associated with poor emergence under direct drilling (Cannell and Ellis 1979). These residues may impair the penetrating ability of the drill and seeds can be buried in contact with straw residues which may decompose with the production of toxins harmful to the germinating seedlings (Ellis 1979).

1.3.2 Root Growth

The root system of cereal crops has no intrinsic economic value; its importance lies in its relationship to the yield bearing portion of the plant. The changed soil conditions found under direct drilling, while mainly affecting root growth, can thus also affect the growth of the shoot. The influence of the root system may be manifest in several ways i.e. by the nutrients and water it supplies, the anchorage it affords and by the resistance it gives to pathogens or toxic levels of minerals (Troughton and Whittington 1969). In recent years it has also been recognized that roots play an essential role in the hormonal control processes on which the growth of the whole plant depends (Vaadia and Itai 1969). In the following discussion the effect of the soil conditions produced under direct drilling on root growth and activity are reviewed. Further examples of the manner in which shoot growth may be influenced by the growth and activity of the root system are reviewed in Section 1.3.3.

Several studies have indicated that the differences in root growth under contrasting cultivation treatments are greatest during the early phases of crop growth (Cannell 1975; Holmes 1976). Early establishment seems to be the most critical stage of root development (Finney 1973), and roots are most susceptible to adverse environmental conditions at this time (Drew and Goss 1973). Although roots have a great capacity for compensatory growth (Crossett, Campbell and Stewart 1975), this may not be enough to overcome the effect of early restrictions to root growth.

In a review of the effects of tillage on root growth Finney (1973) suggested that seminal rooting depth is determined in the first weeks after sowing, when the differences in soil physical conditions between soils under conventional cultivation or direct drilling are most extreme. As seminal roots are usually deepest and nodal roots are usually restricted to the upper soil layers (Weaver 1926; Briggs 1978), any inhibition of early root growth could lead to the development of a shallow root system, which would make the crop more susceptible to adverse environmental conditions, particularly drought.

In addition to the initial effects on crop establishment (see Section 1.3.1), direct drilling gives rise to a number of changes in soil conditions which may affect root growth. After direct drilling soil is often more compact, of greater strength and higher moisture content, has fewer large pores and a lower air filled porosity (see Section 1.2).

Laboratory experiments have frequently shown an inverse linear relationship between soil strength, as measured by penetrometer resistance, and root elongation of a wide range of crop species (Barley, Farrell and Graecen 1965; Eavis 1972; Gooderham and Fisher 1975; El-Karouri 1974). After reviewing the effect of soil strength on root growth Barley and Greacen (1967) suggested that mechanical resistance should be regarded as having a general influence on the growth of roots in all but the most friable soils. Later work by Goss (1977) supports this suggestion. In experiments in which cereal roots were grown in glass beads, he found that relatively small increases in mechanical resistance reduced root elongation.

Thus if root extension is not to be limited by mechanical resistance soil must contain a sufficient number of continuous pores large enough for roots to penetrate freely. However as was discussed in Section 1.2.2, the proportion of pores large enough to allow unimpeded extension of roots may be reduced under direct drilling. The effect of pore size on root elongation was first shown by Wiersum in 1957. In a simple but elegant experiment, using sintered glass discs of different pore size ranges, he showed that roots can only grow through rigid pores of equal or greater diameter than that of root tips. This finding has been confirmed by more recent experiments reported by Goss (1977) in which roots were grown through rigid glass beads, bead size being varied so that the diameter of pores between beads may be greater or smaller than the root diameter of the plant species examined.

Field observations indicate that whenever possible roots grow along earthworm burrows and ramify along planes of weakness in the soil (Russell 1977). The reduction in root growth in compact soil is often correlated with a reduction in the proportion of large pores through which roots can freely grow (Veihmeyer and Hendrickson 1948; Meredith and Patrick 1961). In the absence of pores large enough to allow unimpeded root extension, roots must penetrate soil by expanding pores by exerting a force greater than the mechanical strength of the soil. Thus the decrease in the proportion of large pores and the increase in soil strength in the more compact soil found after direct drilling, may together result in a considerable reduction in root proliferation. However when direct drilling is practiced for a number of years it has been suggested that the effects of compaction on root growth may be ameliorated. Field observations have indicated that channels produced by earthworms, roots and soil cracking may persist longer in the undisturbed soils under direct drilling (Russell 1977). As was previously discussed, roots tend to grow along such channels and thus any increase in their numbers may favour root proliferation. This suggestion is supported by the work of Edwards and Lofty (1978) who examined the influence of earthworms upon root growth of direct drilled cereals. They found that earthworms played an important role in promoting root growth in soil subjected to continuous direct drilling and they concluded that this was probably because earthworms provided channels for root growth.

It has been suggested that the stratification of nutrients found under direct drilling may directly influence root distribution. Laboratory experiments with barley have shown that phosphate enrichment of part of the rooting zone can promote a localised increase in the growth of lateral roots (Drew 1975; Drew and Saker 1978a).

In field experiments the greater concentrations of phosphate and potassium found in the surface soil layers under direct drilling have been associated with greater rooting densities in these layers in direct drilled than in ploughed soils (Drew and Saker 1978b; Drew and Saker 1980). However, as other changes in soil conditions found under direct drilling may also restrict root development to the surface soil layers the direct influence on root growth of any particular factor cannot be conclusively demonstrated. As a further example of this point, attention may be drawn to the suggestion that the development of a shallow root system may also be encouraged by the greater moisture content of soil under direct drilling than under ploughing (Baeumer and Bakermans 1973; Drew and Saker 1980).

### 1.3.3 The Relationship of Roots to Shoots

The shoot and root growth of a plant are controlled by a co-ordinated system characteristic of its genotype. Environmental conditions are then superimposed upon this system such that the reaction is greatest in the directly affected part. This part first profits or suffers more but ultimately the growth pattern is changed to balance contributions from shoot and root to total metabolite synthesis.

Examples of the operation of this control mechanism can be found in work studying the effect of excising part of the root system on the growth of the plant. Brouwer (1963) using beans and oats and Andrews and Newman (1968) using wheat demonstrated that when a portion of the root system is cut off the original shoot/root ratio is soon restored. This return to equilibrium was attained by a reduction in growth of both the shoot and root systems, the reduction in shoot growth being greater than that of root growth.

Shoot/root ratio is not necessarily constant, and may change in response to environmental conditions. For example an increase in shoot/root ratios at low light intensities favours the development of maximum leaf area for light interception by the plant (Brouwer 1977). Schuurman (1971) studied the effects of subsoil density on shoot and root growth of oats. He found that increasing subsoil density progressively reduced shoot/root ratio and this was accompanied by an overall reduction in plant dry weight. A further complication in the interaction of environment with shoot and root growth is that the effect of one environmental factor may be altered by variation in other environmental factors (Russell 1977).

The controlling mechanism by which shoot/root ratio is set and maintained seems likely to involve the action of plant growth hormones. The production and transport of plant growth hormones by roots has been demonstrated by many workers (Drew and Goss 1973; Russell 1977). It is now recognised that environmental influences which affect the root system act not only on water uptake, ion uptake and transport of organic substances, but also on the hormonal flow from root to shoot and *vice versa* (Torrey 1976).

The analysis of the importance of roots simply in terms of the partition of dry matter between roots and shoots is an inadequate framework for the interpretation of all shoot/root interactions. Root activity depends not just on root mass but may also be affected by root morphology, anatomy and physiology. For example Drew and Saker (1975) demonstrated that the provision of favourable concentrations of either phosphate or nitrate to only a limited part of a barley root system growing in solution culture can largely offset a limited supply to other parts of the root system. This compensatory response being due to an increased proliferation of lateral roots in the enriched zone and to greater nutrient uptake per unit root weight in this zone. Similarly in laboratory experiments Goss (1977) reported that although mechanical impedance could restrict root system size, the smaller root system could support a plant if ample nutrients and water were available.

From the above discussion it can be seen that it may be difficult to define the precise conditions under which soil grown root systems are unable to function adequately because:-

a) the conditions prevailing at the soil/root interface may be unknown.
b) the root system may be able to compensate for adverse soil conditions in a particular soil layer by increased root proliferation and activity in other soil layers.

Thus although there may be sufficient evidence to empirically predict the changes in soil conditions which may be expected under direct drilling (Cannell et al 1978) it is more difficult to predict how these changes may affect crop growth and yield.

## 1.4 Suitability of Cereal Varieties for Direct Drilling

Many investigations have been made of the effects of direct drilling on soil conditions and crop growth (see Sections 1.2 and 1.3). The results of investigations made in Britain have been used to provisionally classify soil types for their suitability for sequential direct drilling of combine-harvested crops (Cannell et al 1978). However no studies have been made of the suitability of cereal species and varieties for use in a direct drilling system.

Commercially available cereal varieties have nearly always been bred and selected under the favourable soil conditions found after conventional cultivation. The soil conditions found after direct drilling may be markedly different than after ploughing. It is not known whether the varieties currently available are suited to the soil conditions produced by direct drilling. In the following paragraphs attention is drawn to the known variation in certain plant characters which, it is suggested, could influence the performance of varieties established by direct drilling. Some reference is made to genotypic variation in root growth, although this topic is reviewed more fully in Section 5.

The greatest effects of direct drilling on crop growth are often seen at emergence (see Section 1.3.2). Allan, Vogel and Peterson (1962) found that the emergence rates of winter wheat varieties were related to coleoptile length; semi-dwarf varieties had short coleoptiles and tended to have poorer emergence. Thus some semi-dwarf varieties may be at an initial disadvantage due to their poor emergence and this may be compounded by the adverse effects of direct drilling on emergence with the result that their growth under direct drilling may be poorer than expected.

Wheat and barley varieties are currently being bred with reduced shoot height. This is mainly achieved by a reduction in length of the lower part of the shoot, that is of organs normally supplying roots with assimilates (Mackey 1973). Thus, as Evans and Dunstone (1970) suggest, the development of high yielding cereals may have been associated with a progressive decrease in root growth relative to shoot growth. After direct drilling root growth is frequently restricted (see Section 1.3.2); the root growth of a variety with an inherently small root system could be restricted to such an extent that it was no longer able to supply the plant with sufficient nutrients and water.

Karmacharya (1973) found that the root growth of spring wheat cultivars can be related to their culm length. In three varieties decreasing culm length was associated with a smaller root system. However Mex 26, a Mexican dwarf cultivar, had the best developed root system and the shortest culm. Thus variation in wheat root systems need not always be associated with culm length. Even between non-dwarf wheat varieties Pinthus and Eshel (1962) found significant differences in the total length of seminal roots, the number of adventitious roots and root distribution.

Laboratory studies have also indicated that variation in some root morphological and physiological characteristics could influence the performance of varieties established by direct drilling. The variation in these root characters and the effect this has on crop interaction with environment are reviewed in Section 5.

# PART I

# FIELD EXPERIMENTS

## SECTION 2

## METHODS

# 2. METHODS

## 2.1 Introduction

In 1975-76 three experiments were made to investigate the response to a change from traditional seedbeds to direct drilling of contrasting cultivars of:

- spring cereal species and cultivars
- winter wheat cultivars
- spring barley cultivars

In 1977 the experiment using spring barley cultivars was repeated at a different site. All experiments also included a comparison of different methods of fertiliser application.

## 2.2 Experimental Designs

All experiments were designed as randomised blocks with split plots, with tillage in main plots and cereal cultivars and fertiliser application methods in sub-plots. A summary of the treatments in each experiment is given in Table 2.1.

## 2.3 Site Descriptions

A summary of site descriptions is given in Table 2.2. Weather data from meteorological stations close to the experimental sites are given in Tables 2.8 and 2.9.

## 2.4 Experimental Materials

The cereal cultivars were selected for diversity either of origin or of phenotypic characteristics. In particular differences in plant height were used in selection as previous work indicated that this character may be correlated with the size of the root system (see section 1). A summary of the source and characteristics of cultivars used in the field experiments is given in Table 2.3.

## 2.5 Agronomy

The field operations are presented as a calendar for each experiment (Tables 2.4 to 2.7). All trials were drilled with a triple disc Fernhurst drill, extra weights were fitted for direct drilling. Sowing depth was controlled by pressure transmitted to the coulters from an hydraulic ram linked to the hydraulic system of the tractor. Plots were harvested using a Class plot combine, with a 2 metre cutting width, fitted with a weighing hopper.

## 2.6 Crop Sampling

A strip 2 metres wide was left unsampled down the centre of each plot. After allowing for this the row and place within row to be sampled were chosen randomly.

Shoot dry matter production was estimated from samples at particular stages of growth. The dry samples were ground and their percentage nitrogen content determined by the Central Analytical Laboratory of the Edinburgh School of Agriculture. Pre-harvest samples were used to determine the numbers of fertile and infertile shoots, the number of grains per ear and the mean ear and stem weights. Grain samples were taken at harvest and used to determine 1,000 grain weights, dry matter percentage and percentage nitrogen content.

TABLE 2.1 EXPERIMENTAL TREATMENTS

| EXPERIMENT | TREATMENTS |
|---|---|
| Spring cereal species and cultivars (1976) | Tillage<br>Direct drilling or ploughing to 15 cm.<br>Fertiliser Application<br>Fertiliser combine drilled with seed or broadcast from fertiliser hopper of seed drill.<br>Cultivars<br>Spring barley: Midas, Zephyr, Georgie.<br>Spring wheat: Sirius, Sicco.<br>Spring oats: Nelson, Leanda.<br>Spring rye: Somro. |
| Spring barley cultivars (1976 and 1977) | Tillage<br>As for spring cereal species and cultivars.<br>Fertiliser Application<br>As for spring cereal species and cultivars.<br>Cultivars<br>Clermont, Georgie, Maris Mink. |
| Winter wheat cultivars (1976) | Tillage<br>Direct drilling or ploughing to 18 cm.<br>Fertiliser Application<br>Single application of nitrogen in spring or split autumn, spring application of same quantity of nitrogen.<br>Cultivars<br>Maris Fundin, Maris Widgeon, Mega. |

TABLE 2.2 SITE DESCRIPTIONS

| YEAR | 1976 | 1975-76 | 1976 | 1977 |
|---|---|---|---|---|
| Experiment | Spring cereal species and cultivars | Winter wheat cultivars | Spring barley cultivars | Spring barley cultivars |
| Farm | Edinburgh University Boghall Farm | Clifton Mains Newbridge, Midlothian | | Edinburgh University Langhill Farm |
| Field | Hay Knowes | West Howdales | | Kilburn |
| Grid reference | 248649 | 114703 | | 268638 |
| Slope | 1° | 10° | | 1° |
| Aspect | Western | Northern | | South-Eastern |
| Height (m) | 190 | 76 | | 150 |
| Previous cropping | Barley (1971)<br>Grass (1972-73)<br>Potatoes (1974)<br>Barley (1975) | Barley (1971 to 1975) | | Grass (1972-73)<br>Barley (1974)<br>Potatoes (1975)<br>Wheat (1976) |
| Soil texture | Clay loam | Sandy clay loam | | Sandy loam |
| Soil series (Soil survey of Scotland) | MacMerry | Queensferry soil complex | | MacMerry |
| Soil analyses | pH 6.39<br>P 4.8 ML<br>K 163.5 M<br>Mg 246 MH | pH 6.4<br>P 15.1 MH<br>K 281 H<br>Mg 184 MH | | pH 6.1<br>P 3.5 ML<br>K 71 L<br>Mg 142 M |

KEY

The concentrations of P, K and Mg are given in milligrammes per kilogramme of soil.

Soil Nutrient Status H = High, MH = Medium High<br>M = Medium<br>L = Low, ML = Medium Low

TABLE 2.3 CULTIVARS USED IN EXPERIMENTS

BARLEY VARIETIES

| | |
|---|---|
| Clermont | (Boridia x Kenia) x Frisia, Institut National de la Recherche Agronomique, Versailles, France. Six row barley. |
| Maris Mink | Deba Abed x (Emir x Swallow) PBI Cambridge. Has been high yielding with a short, strong straw. Matures late and is susceptible to *Rhynchosporium*. Mildew resistant. |
| Georgie (RPB 38/69) | Vada x Zephyr from Rothwell, Grimsby. Very high yielding barley with moderately strong, short straw. Good brown rust resistance, moderate *Rhynchosporium* resistance. Average maturing. |
| Midas | [(Proctor x Wong) x Mildew Resistant "A"] x Golden Promise. Short straw, good resistance to lodging. Late ripening. Moderate mildew resistance, very susceptible to brown rust. |
| Zephyr | H 2149 x Carlsberg from M.G.H., Holland. High yield, good malting quality, moderately stiff straw, straw of slightly longer than average. May suffer "ear loss" when over-ripe, and the grains have a tendency to split. Average maturing. |

TABLE 2.3 (cont.)

| | |
|---|---|
| WHEAT VARIETIES | |
| WINTER I | |
| Maris Fundin | [(Vilmorin 20 x Vg 8058) x Capelle] x [(CI 12633 x Capelle) x (Heine 110 x Capelle)] x Nord Desprez from PBI, Cambridge. A semi-dwarf, grain of poor appearance. Yield high in trials. Good mildew resistance, very slightly late maturing. |
| Mega | (Capelle-Desprez x H 2596) x 6003 from Rothwell, Grimsby. Average yield, stiff straw of average length, good disease resistance. |
| Maris Widgeon | Holdfast x Capelle Desprez, PBI Cambridge. Combines good yield, high resistance to eyespot and very high milling and bread-making quality. Straw rather long. Susceptible to loose smut. |
| SPRING II | |
| Sirius | Bavarian variety x Probat from von Rünher Germany. High yield with very early maturity and very short stiff straw. Very high milling and high bread making quality. Liable to shed when over-ripe. |
| Sicco | Ring x (Opal x Selkirk), Cebeco, Holland. High yield, short stiff straw, good disease resistance particularly to mildew. |
| SPRING OAT VARIETIES 1976 | |
| Nelson | Complex cross involving five varieties, Wiebull, Sweden. High yield and moderately stiff straw. Mildew resistance at present very good. Good resistance to crown rust and the two important pathotypes of cereal cyst eelworm. |
| Leanda | Condor x Cebeco 725 from Cebeco, Holland. Short strawed, average maturity and standing ability. Moderate mildew resistance (good for oats). |
| SPRING RYE VARIETY | |
| Somro | No information available. |

TABLE 2.4 CALENDAR: SPRING CEREAL SPECIES AND CULTIVARS 1976

| | |
|---|---|
| 16th February | Ploughing to 15 centimetres. |
| 5th April | Direct drilled plots sprayed with paraquat (Gramoxone W) at 5.6 litres/hectare using Dorman Osprey Wheelaway Market Garden Sprayer. |
| 12th April | Trial sown. Seed rate 224 kg/ha. Fertiliser either broadcast or combine drilled at time of sowing: 80 kg N/ha and 40 kg $P_2O_5$ and $K_2O_4$ /ha as 20:10:10. An additional 75 kg N/ha as Nitrochalk (26% N) was broadcast on all plots. |
| 14th May | Shoot sample, 4 x 1 m strips of crop row per plot. |
| 18th May | Plant counts, 5 x 1 m strips of crop row per plot. |
| 27th May | Trial sprayed with bromoxynil (Tetroxone) at 0.92 l/ha. |
| 28th May | Shoot sample, 2 x 1 m strips of crop row per plot. |
| 8th June | Shoot sample, 2 x 1 m strips of crop row per plot. |
| 23rd June | Shoot sample, 2 x 1 m strips of crop row per plot. |
| 15th August | Measurement of crop height. |
| 20th August | Pre-harvest sample, 5 x 1 m strips of crop row per plot. |
| 1-7th September | Trial harvesting staggered as cultivars ripened at different times. Samples of harvested grain taken to determine 1,000 grain weight and moisture content. |

TABLE 2.5 CALENDAR: WINTER WHEAT CULTIVARS (1975-76)

| | |
|---|---|
| 15th October 1975 | Direct drilled plots sprayed with paraquat (Gramoxone W) at 2.8 l/ha. |
| 23rd October | Ploughing to 18 cm. |
| 24th October | Trial sown. Seed rate 270 kg/ha. 50 kg $P_2O_5$ and $K_2O_4$/ha as 0:20:20 combine drilled with seed. 52 kg N/ha as Nitrochalk (26% N) broadcast on plots receiving split Nitrogen application. |
| 12th December | Plant counts, 5 x 1 m strips of crop row per plot. |
| 7th March 1976 | 78 kg N/ha as Nitrochalk (26% N) broadcast on plots receiving split Nitrogen application. 130 kg N/ha as Nitrochalk (26% N) applied to plots receiving single Nitrogen application. |
| 4th August | Measurement of crop height. |
| 19th August | Trial harvested. |

TABLE 2.6 CALENDAR: SPRING BARLEY CULTIVARS 1976

| | |
|---|---|
| 5th February | Ploughing to 15 cm. |
| 2nd March | Direct-drilled plots sprayed with paraquat (Gramoxone W) at 4.2 l/ha. |
| 7th March | Ploughed plots harrowed. |
| 8th March | Trial sown. Seed rate 190 kg/ha. 75 kgN 33 kg $P_2O_5$ and $K_2O_4$ per hectare as 20:10:10 combine drilled or broadcast at time of sowing. Plots harrowed across direction of drilling. |
| 23rd April | Plant counts 5 x 1 m strips of crop row per plot. Top dressing of 40 kgN/ha applied on Nitrochalk (26% N). |
| 14th June | Shoot sample 2 x 1 m strips crop row per plot. |
| 28th June | Trial sprayed with $MnSO_4$, triclemorph (Calixin) and carbendazim (Bavistin). |
| 4th August | Preharvest sample 5 x 1 m strips of crop row per plot. Canopy height measured. |
| 10th-19th August | Harvest staggered due to differential ripening of cultivars. |

TABLE 2.7 CALENDAR: SPRING BARLEY CULTIVARS 1977

| | |
|---|---|
| 9th-10th March | Ploughing to 15 cm. |
| 25th March | Direct-drilled plots sprayed with paraquat (Gramoxone W) at 4.2 l/ha. |
| 9th April | Trial sown. Seed rate 240 kg/ha. 100 kgN, 50 kg $P_2O_5$ and $K_2O_4$/hectare as 20:10:10 combine drilled or broadcast at time of sowing. |
| 13th May | Plant counts 2 x 1 m strips of crop row per plot. |
| 4th July | Shoot samples 2 x 1 m strips crop row per plot. |
| 5th September | Trial harvested. |

TABLE 2.8

WEATHER RECORDS
AT BUSH ESTATE METEOROLOGICAL STATION
(nearest station to Boghall and Langhill Farms)

| | | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Potential | 1975 | | | | | | | | | | 15.3 | 4.1 | 6.4 |
| Evapotranspiration | 1976 | 4.8 | 9.2 | 21.9 | 41.0 | 61.5 | 84.0 | 87.3 | 65.3 | 32.6 | 12.2 | 0 | 0 |
| (mm) | 1977 | 0 | 2.8 | 24.4 | 49.1 | 67.8 | 75.2 | 81.2 | 59.8 | 33.8 | | | |
| | Average 1956–75 | 6.1 | 12.0 | 29.1 | 45.5 | 66.8 | 81.7 | 78.3 | 62.6 | 37.7 | 18.8 | 6.2 | 7.3 |
| Rainfall (mm) | 1975 | | | | | | | | | 176.9 | 31.6 | 30.0 | 12.6 |
| | 1976 | 68.2 | 41.1 | 70.7 | 73.0 | 61.7 | 26.0 | 46.1 | 27.2 | 73.0 | 157.1 | 51.0 | 58.6 |
| | 1977 | 97.2 | 76.7 | 83.3 | 40.6 | 44.5 | 121.8 | 14.6 | 117.2 | 76.6 | 100.0 | 97.4 | 49.3 |
| | Average 1955–79 | 68.6 | 52.6 | 60.0 | 49.1 | 56.9 | 51.5 | 77.4 | 86.1 | 72.1 | 73.6 | 79.9 | 77.9 |
| Monthly | 1975 | | | | | | | | | 116.4 | 75.2 | 52.9 | 31.1 |
| Sunshine | 1976 | 43.5 | 31.6 | 93.8 | 108.5 | 113.2 | 165.1 | 191.9 | 178.6 | 63.4 | 71.9 | 69.5 | 55.1 |
| (Hours) | 1977 | 53.9 | 63.3 | 64.6 | 140.0 | 179.1 | 163.1 | 175.0 | 151.8 | 85.6 | 96.4 | 64.0 | 39.5 |
| | Average 1955–79 | 40.1 | 64.4 | 94.2 | 128.5 | 155.0 | 162.5 | 137.5 | 137.3 | 106.3 | 85.8 | 52.1 | 30.7 |
| Mean Daily | 1975 | | | | | | | | | 7.5 | 5.5 | 2.0 | 2.7 |
| Minimum | 1976 | 1.8 | 1.5 | 0.5 | 3.2 | 6.2 | 9.7 | 10.9 | 9.1 | 8.4 | 5.4 | 2.0 | -1.4 |
| Temperature (°C) | 1977 | -1.4 | -0.2 | 2.2 | 2.7 | 3.6 | 6.6 | 9.8 | 8.9 | 7.8 | 7.0 | 1.4 | 2.2 |
| | Average 1955–79 | -0.4 | -0.8 | 1.0 | 2.4 | 4.8 | 8.0 | 9.5 | 9.4 | 8.0 | 5.7 | 1.9 | 0.8 |
| Mean Daily | 1975 | | | | | | | | | 14.2 | 12.1 | 7.7 | 7.9 |
| Maximum | 1976 | 6.6 | 6.0 | 6.9 | 9.8 | 13.5 | 18.2 | 20.3 | 19.5 | 19.0 | 11.6 | 7.7 | 2.9 |
| Temperature (°C) | 1977 | 3.6 | 4.7 | 8.0 | 9.1 | 12.6 | 15.1 | 18.2 | 16.8 | 14.0 | 13.3 | 7.2 | 7.1 |
| | Average 1955–79 | 4.9 | 5.0 | 7.2 | 9.9 | 13.1 | 16.3 | 16.3 | 17.3 | 15.1 | 12.3 | 7.8 | 5.9 |

TABLE 2.9

<u>WEATHER RECORDS</u>
<u>AT TURNHOUSE AIRPORT METEOROLOGICAL STATION</u>
<u>(nearest station to Clifton Mains Farm)</u>

| | | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Potential Evapotranspiration (mm) | 1975 | | | | | | | | | 50.4 | 22.1 | 7.1 | 7.1 |
| | 1976 | 14.6 | 19.9 | 34.2 | 52.2 | 74.4 | 100.2 | 101.8 | 76.8 | 47.6 | 22.0 | | |
| | Average 1956-75 | 6.4 | 11.8 | 32.1 | 51.9 | 74.7 | 88.7 | 82.7 | 66.5 | 41.0 | 21.5 | 6.3 | 5.3 |
| Rainfall (mm) | 1975 | | | | | | | | | 126.1 | 29.5 | 27.1 | 8.2 |
| | 1976 | 39.3 | 25.2 | 52.9 | 43.8 | 57.1 | 28.0 | 39.0 | 21.6 | 77.2 | 123.7 | | |
| | Average 1941-70 | 53 | 43 | 39 | 40 | 58 | 47 | 72 | 82 | 65 | 59 | 64 | 55 |
| Monthly Sunshine (Hours) | 1975 | | | | | | | | | 109.6 | 75.3 | 66.3 | 52.6 |
| | 1976 | 48.1 | 32.2 | 85.8 | 115.1 | 123.8 | 168.3 | 209.9 | 195.3 | 75.6 | 79.5 | | |
| | Average 1941-70 | 44.1 | 71.7 | 98.3 | 143.4 | 173.3 | 177.3 | 156.8 | 136.8 | 111.8 | 88.2 | 52.8 | 39.7 |
| Mean Daily Minimum Temperature ($^{o}$C) | 1975 | | | | | | | | | 8.1 | 6.5 | 3.0 | 3.6 |
| | 1976 | 2.5 | 2.8 | 1.5 | 4.1 | 6.9 | 10.6 | 11.5 | 10.2 | 9.6 | 7.0 | | |
| | Average 1941-70 | 0.1 | 0.0 | 1.7 | 3.3 | 5.7 | 8.6 | 10.3 | 10.0 | 8.5 | 6.3 | 2.7 | 1.3 |
| Mean Daily Maximum Temperature ($^{o}$C) | 1975 | | | | | | | | | 15.8 | 13.2 | 8.8 | 8.2 |
| | 1976 | 7.3 | 7.5 | 7.8 | 11.3 | 14.6 | 19.8 | 21.1 | 20.2 | 15.6 | 12.9 | | |
| | Average 1941-70 | 5.4 | 6.2 | 8.6 | 11.5 | 14.0 | 17.1 | 18.5 | 18.1 | 16.3 | 13.0 | 8.7 | 6.4 |

# PART I

# FIELD EXPERIMENTS

## SECTION 3

## RESULTS

# 3. RESULTS

The results from these trials are presented in the following section. In Tables 3.1 to 3.38 the letters V, F, C refer to treatment comparisons; V between cultivars, F between fertilisation treatments and C between cultivation (tillage) treatments, interactions being indicated by combinations of these letters. Asterisks refer to the level of significance of a difference, *** ($P < .001$) ** ($P < .01$) * ($P < .05$) and ns (no statistical significance). In the following section where a difference is said to be significant this means that it is statistically significant.

## 3.1 Spring Cereal Species and Cultivars Experiment

### 3.1.1 Grain Yield and its Components (Tables 3.1 to 3.4)

Overall direct drilling gave lower yields irrespective of the cereal species or cultivar, though this direct comparison was not the main consideration and was not measured with precision in the design used for this experiment. The only significant differences in yield were between cereal species and cultivars; the spring barley and spring rye cultivars had heavier grain yields than the wheat and oat cultivars. At harvest most species/cultivars had a slightly greater yield after combine-drilling of seedbed fertiliser, though some cultivars (Somro, Nelson, Zephyr) produced slightly greater yields after broadcast fertiliser application.

The number of ears, grains per ear and the 1,000 grain weights all showed no significant differences in main effects or interactions under the tillage and fertilisation treatments. Again the only significant differences were found between species/cultivars.

Thus although there were no significant differences in grain yield and its components there was little evidence of interactions between the yield of species/cultivars with method of tillage or fertilisation. Corrected PLB 2/7/81.

3.1.2 Emergence and Growth (Tables 3.5 to 3.12)

A month after sowing plant counts showed a significant difference in emergence between species and cultivars and a significant interaction of species/cultivars and tillage (Table 3.6). The spring barley Zephyr and the spring wheat Sirius emerged equally well on both tillage treatments, all other cultivars particularly the oat varieties Nelson and Leanda had fewer plants emerged under direct drilling.

At the first shoot sampling on 14th May there were significant differences in crop dry weight; the spring rye Somro had produced 40% more dry matter than the other species/cultivars (Table 3.7). The species/cultivar differences in dry matter production persisted through the growing season. By the 28th May mean crop dry weight had increased five-fold and there were significant differences between tillage and fertilisation treatments and a significant interaction of tillage with species and cultivars (Table 3.8). This interaction was due to Zephyr having a similar dry weight under both tillage treatments while all other species/cultivars had greater yields under ploughing. The significant differences in crop dry weight between tillage and fertilisation treatments were also found on the 8th June although by this time all species and cultivars had produced most dry matter under ploughing (Table 3.9). By the 28th June the differences in crop dry weight between tillage and cultivation treatments were no longer significant (Table 3.10).

At the preharvest sampling on 15th August, although there were significant differences in stem dry weight between species/cultivar and fertilisation treatments there were no significant differences in ear dry weight (Tables 3.11 and 3.12). The significant difference in stem dry weight between fertilisation treatments was accompanied by a significant tillage, fertilisation interaction; stem dry weight was the same after direct drilling under both fertilisation treatments; under ploughing shoot dry weight was greater after combine-drilling.

3.1.3 Nitrogen Uptake (Tables 3.13 to 3.18)

There were no significant differences in % nitrogen in shoot dry matter between agronomic treatments at all three sample dates, although on the 8th and 23rd June there were significant differences between species and cultivars. On the 23rd June there was also a significant interaction of tillage and species/cultivars with respect to % nitrogen in shoot dry matter (Tables 3.13 to 3.15).

The greatest effects on nitrogen uptake were found on the 28th May when there were significant differences in uptake between fertilisation methods and species/cultivars; there were also significant interactions of tillage with fertilisation and of species/cultivars with fertilisation (Table 3.16). By the 8th June the magnitude of differences in nitrogen uptake had decreased and although there were still significant differences in uptake between fertilisation methods and species/cultivars there were no significant interactions (Table 3.17). On the 23rd June the small treatment effects were not significant (Table 3.18).

TABLE 3.1 SPECIES/CULTIVAR TRIAL 1976
Grain yield at 15% moisture content (tonnes/ha) 7.9.76

(i) Cultivation v. Variety

± 0.179

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 3.60 | 3.53 | 2.83 | 3.09 | 2.72 | 2.55 | 4.04 | 4.12 | 3.31 |
| Ploughed | 4.20 | 4.80 | 3.04 | 3.73 | 2.54 | 2.76 | 4.61 | 4.70 | 3.80 |
| Mean | 3.90 | 4.17 | 2.94 | 3.41 | 2.65 | 2.66 | 4.32 | 4.41 | 3.56 |

± 0.164

In table SED vertical comp. = 0.397 SED horiz. comp. = 0.328

C ns V*** CV ns

(ii) Fertilisation v. Variety

± 0.082

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 3.88 | 4.24 | 3.18 | 3.48 | 2.51 | 2.86 | 4.24 | 4.50 | 3.61 |
| Broadcast | 3.92 | 4.10 | 2.69 | 3.34 | 2.80 | 2.45 | 4.40 | 4.32 | 3.50 |
| Mean | 3.90 | 4.17 | 2.94 | 3.41 | 2.65 | 2.66 | 4.32 | 4.41 | 3.56 |

± 0.164

In table SED = 0.328

F ns V*** FV ns

(iii) Fertilisation v. Cultivation

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 3.30 | 3.32 | 3.31 |
| Ploughed | 3.92 | 3.69 | 3.80 |
| Mean | 3.61 | 3.50 | 3.56 |

± 0.179

± 0.082

In table SED vertical comp. = 0.278 SED horiz. comp. = 0.164

F ns C ns FC ns

TABLE 3.2 SPECIES/CULTIVAR TRIAL 1976
Number of stems with ears per metre crop row 15.8.76

(i) Cultivation v. Species/Cultivar

± 1.9

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 94 | 88 | 73 | 75 | 65 | 72 | 77 | 82 | 78 |
| Ploughed | 100 | 103 | 82 | 76 | 75 | 71 | 72 | 102 | 85 |
| Mean | 97 | 96 | 77 | 76 | 70 | 71 | 75 | 92 | 82 |

± 1.9

In table SED vertical comp. = 8.0 SED horiz. comp. = 8.0

C ns V*** CV ns

(ii) Fertilisation v. Species/Cultivar

± 2.0

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 102 | 95 | 79 | 73 | 67 | 68 | 71 | 102 | 82 |
| Broadcast | 92 | 96 | 76 | 79 | 73 | 74 | 79 | 82 | 81 |
| Mean | 97 | 96 | 77 | 76 | 70 | 71 | 75 | 92 | 82 |

± 1.9

In table SED = 8.13

F ns V*** FV ns

(iii) Fertilisation v. Cultivation

± 1.9

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 80 | 77 | 78 |
| Ploughed | 85 | 86 | 85 |
| Mean | 82 | 81 | 82 |

± 2.0

In table SED vertical comp. = 4.0 SED horiz. comp. = 4.1

F ns C ns FC ns

TABLE 3.3 SPECIES/CULTIVAR TRIAL 1976
Number of grains per ear 15.8.76

(i) Cultivation v. Species/Cultivar

± 2.26

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 19.7 | 20.8 | 22.9 | 30.0 | 39.4 | 44.8 | 27.3 | 18.8 | 28.0 |
| Ploughed | 20.0 | 22.2 | 25.0 | 30.8 | 43.2 | 48.3 | 31.3 | 18.9 | 30.0 |
| Mean | 19.9 | 21.5 | 24.0 | 30.4 | 41.3 | 46.6 | 29.3 | 18.9 | 29.0 |

± 1.98

In table SED vertical comp. = 4.88 SED horiz. comp. = 3.95

C ns V*** CV ns

(ii) Fertilisation v. Species/Cultivar

± 0.99

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 19.7 | 21.8 | 23.1 | 29.5 | 41.2 | 45.2 | 29.6 | 18.7 | 28.6 |
| Broadcast | 20.1 | 21.2 | 24.8 | 31.4 | 41.3 | 47.9 | 28.9 | 19.1 | 29.3 |
| Mean | 19.9 | 21.5 | 24.0 | 30.4 | 41.3 | 46.6 | 29.3 | 18.9 | 29.0 |

± 1.98

In table SED = 3.95

F ns V*** FV ns

(iii) Fertilisation v. Cultivation

± 2.26

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 27.4 | 28.5 | 28.0 |
| Ploughed | 29.8 | 30.2 | 30.0 |
| Mean | 28.6 | 29.3 | 29.0 |

± 0.99

In table SED vertical comp. = 3.48 SED horiz. comp. = 1.98

F ns C ns FC ns

TABLE 3.4 SPECIES/CULTIVAR TRIAL 1976
1,000 grain weights (g) 15.8.76

(i) Cultivation v. Variety

± 1.07

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 37.4 | 35.6 | 31.7 | 30.2 | 25.9 | 25.8 | 30.0 | 39.1 | 32.0 |
| Ploughed | 36.9 | 32.7 | 31.8 | 31.1 | 24.7 | 24.6 | 31.6 | 38.0 | 31.4 |
| Mean | 37.2 | 34.1 | 31.7 | 30.6 | 25.3 | 25.2 | 30.8 | 38.6 | 31.7 |

± 1.19

In table SED vertical comp. = 2.69 SED horiz. comp. = 2.38

C ns V*** CV ns

(ii) Fertilisation v. Variety

± 0.59

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 38.8 | 34.2 | 31.8 | 32.3 | 25.5 | 25.3 | 30.9 | 40.5 | 32.4 |
| Broadcast | 35.5 | 34.0 | 31.7 | 29.0 | 25.1 | 25.1 | 30.7 | 36.6 | 31.0 |
| Mean | 37.2 | 34.1 | 31.7 | 30.6 | 25.3 | 25.2 | 30.8 | 38.6 | 31.7 |

± 1.19

In table SED = 2.38

F ns V*** FV ns

(iii) Fertilisation v. Cultivation

± 1.07

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 32.4 | 31.5 | 32.0 |
| Ploughed | 32.4 | 30.4 | 31.4 |
| Mean | 32.4 | 31.0 | 31.7 |

± 0.59

In table SED vertical comp. = 1.73 SED horiz. comp. = 1.19

F ns C ns FC ns

TABLE 3.5 SPECIES/CULTIVAR TRIAL 1976
Number of stems per metre crop row 15.8.76

(i) Cultivation v. Species/Cultivar

± 1.6

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 96 | 91 | 76 | 76 | 67 | 73 | 79 | 84 | 80 |
| Ploughed | 100 | 104 | 84 | 80 | 77 | 73 | 74 | 102 | 87 |
| Mean | 98 | 97 | 80 | 78 | 72 | 73 | 77 | 93 | 84 |

± 4.1

In table SED vertical comp. = 8.0 SED horiz. comp. = 8.1

C ns V* CV ns

(iii) Fertilisation v. Species/Cultivar

± 2.0

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 104 | 95 | 82 | 75 | 69 | 69 | 73 | 104 | 84 |
| Broadcast | 92 | 99 | 78 | 81 | 75 | 77 | 81 | 83 | 83 |
| Mean | 98 | 97 | 80 | 78 | 72 | 73 | 77 | 93 | 84 |

± 4.1

In table SED = 8.1

F ns V* FV ns

(iii) Fertilisation v. Cultivation

± 1.6

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 82 | 79 | 80 |
| Ploughed | 86 | 88 | 87 |
| Mean | 84 | 83 | 84 |

± 2.0

In table SED vertical comp. = 3.7 SED horiz. comp. = 4.1

F ns C ns FC ns

TABLE 3.6 SPECIES/CULTIVAR TRIAL 1976
Emergence 18.5.76
(number of plants per metre of crop row)

(i) Cultivation v. Variety

± 0.75

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 47.0 | 43.8 | 54.2 | 48.0 | 50.4 | 48.5 | 54.1 | 42.0 | 48.5 |
| Ploughed | 47.4 | 49.0 | 53.7 | 51.6 | 63.2 | 76.2 | 61.6 | 47.9 | 56.3 |
| Mean | 47.2 | 46.4 | 53.9 | 49.8 | 56.8 | 62.3 | 57.8 | 45.0 | 52.4 |

± 2.13

In table SED vertical comp. = 4.13 SED horiz. comp. = 4.27

C ns V*** CV**

(ii) Fertilisation v. Variety

± 1.07

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 47.0 | 50.6 | 54.4 | 47.9 | 58.6 | 59.8 | 56.2 | 46.1 | 52.6 |
| Broadcast | 47.4 | 42.4 | 53.4 | 51.6 | 55.1 | 65.0 | 59.6 | 43.8 | 52.3 |
| Mean | 47.2 | 46.4 | 53.9 | 49.8 | 56.8 | 62.4 | 57.8 | 45.0 | 52.4 |

± 2.13

In table SED = 4.27

F ns V*** FV ns

(iii) Fertilisation v. Cultivation

± 0.75

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 48.7 | 48.3 | 48.5 |
| Ploughed | 56.4 | 56.2 | 56.3 |
| Mean | 52.6 | 52.3 | 52.4 |

± 1.07

In table SED vertical comp. = 1.84 SED horiz. comp. = 2.13

F ns C ns FC ns

TABLE 3.7 SPECIES CULTIVAR TRIAL 1976
Shoot dry matter production 14.5.76
(grammes per metre of crop row)

(i) Cultivation v. Variety

± 0.075

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 1.39 | 1.25 | 1.42 | 0.97 | 1.33 | 1.33 | 1.95 | 1.35 | 1.37 |
| Ploughed | 1.74 | 1.72 | 1.64 | 1.45 | 1.97 | 2.14 | 2.74 | 2.09 | 1.94 |
| Mean | 1.56 | 1.48 | 1.53 | 1.21 | 1.65 | 1.73 | 2.34 | 1.72 | 1.66 |

± 0.094

In table SED vertical comp. = 0.205 SED horiz. comp. = 0.188

C ns V*** CV ns

(ii) Fertilisation v. Variety

± 0.047

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 1.73 | 1.64 | 1.62 | 1.24 | 1.72 | 1.76 | 2.34 | 1.87 | 1.74 |
| Broadcast | 1.40 | 1.33 | 1.44 | 1.18 | 1.58 | 1.70 | 2.34 | 1.57 | 1.57 |
| Mean | 1.56 | 1.48 | 1.53 | 1.21 | 1.65 | 1.73 | 2.34 | 1.72 | 1.66 |

± 0.094

In table SED = 0.188

F* V*** FV ns

(iii) Fertilisation v. Cultivation

± 0.075

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 1.42 | 1.33 | 1.37 |
| Ploughed | 2.06 | 1.81 | 1.94 |
| Mean | 1.74 | 1.57 | 1.66 |

± 0.047

In table SED vertical comp. = 0.125 SED horiz. comp. = .094

F* C ns FC ns

TABLE 3.8 SPECIES CULTIVAR TRIAL 1976
Shoot dry matter production 28.5.76
(grammes per metre of crop row)

(i) Cultivation v. Variety

± 0.20

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 8.16 | 6.25 | 5.59 | 5.81 | 6.73 | 6.91 | 12.02 | 6.54 | 7.25 |
| Ploughed | 8.87 | 9.31 | 11.44 | 8.46 | 10.71 | 10.78 | 19.82 | 13.24 | 11.58 |
| Mean | 8.52 | 7.78 | 8.52 | 7.13 | 8.72 | 8.85 | 15.92 | 9.89 | 9.42 |

± 0.70

In table SED vertical comp. = 1.34 SED horiz. comp. = 1.40

C* V*** CV*

(iii) Fertilisation v. Variety

± 0.35

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 11.22 | 8.72 | 9.29 | 8.65 | 9.20 | 9.38 | 15.25 | 11.47 | 10.40 |
| Broadcast | 5.82 | 6.83 | 7.75 | 5.61 | 8.24 | 8.31 | 16.59 | 8.31 | 8.43 |
| Mean | 8.52 | 7.78 | 8.52 | 7.13 | 8.72 | 8.85 | 15.92 | 9.89 | 9.42 |

± 0.70

In table SED = 1.40

F*** V*** FV ns

(iii) Fertilisation v. Cultivation

± 0.20

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 8.16 | 6.35 | 7.25 |
| Ploughed | 12.64 | 10.52 | 11.58 |
| Mean | 10.40 | 8.43 | 9.42 |

± 0.35

In table SED vertical comp. = 0.57 SED horiz. comp. = 0.70

F*** C* FC ns

TABLE 3.9 SPECIES/CULTIVAR TRIAL 1976

Shoot dry matter production 8.6.76
(grammes per metre of crop row)

(i) Cultivation v. Variety

± 0.47

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 17.2 | 18.4 | 17.2 | 12.3 | 22.0 | 15.0 | 32.2 | 23.4 | 19.7 |
| Ploughed | 32.2 | 29.6 | 27.4 | 20.4 | 30.0 | 25.9 | 46.9 | 31.0 | 30.4 |
| Mean | 24.8 | 24.0 | 22.3 | 16.3 | 26.0 | 20.4 | 39.6 | 27.2 | 25.1 |

± 2.01

In table SED vertical comp. = 3.82 SED horiz. comp. = 4.03

C* V*** CV ns

(ii) Fertilisation v. Variety

± 1.00

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 29.4 | 26.3 | 27.6 | 13.9 | 26.5 | 22.0 | 45.9 | 30.9 | 27.8 |
| Broadcast | 20.1 | 21.7 | 17.0 | 18.8 | 25.6 | 18.9 | 33.2 | 23.6 | 22.4 |
| Mean | 24.8 | 24.0 | 22.3 | 16.3 | 26.0 | 20.4 | 39.6 | 27.2 | 25.1 |

± 2.01

In table SED = 4.03

F*** V*** FV ns

(iii) Fertilisation v. Cultivation

± 0.47

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 23.2 | 16.3 | 19.7 |
| Ploughed | 32.4 | 28.4 | 30.4 |
| Mean | 27.8 | 22.4 | 25.1 |

± 1.00

In table SED vertical comp. = 1.57 SED horiz. comp. = 2.01

F*** C* FC ns

TABLE 3.10 SPECIES/CULTIVAR TRIAL 1976

Shoot dry matter production 23.6.76
(grammes per metre of crop row)

(i) Cultivation v. Variety

± 3.27

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 70.6 | 53.6 | 56.7 | 46.0 | 57.0 | 54.8 | 75.3 | 54.6 | 58.6 |
| Ploughed | 76.4 | 75.6 | 74.7 | 61.8 | 80.0 | 74.1 | 103.7 | 73.9 | 77.6 |
| Mean | 73.5 | 64.7 | 65.7 | 53.9 | 68.5 | 64.5 | 89.5 | 64.2 | 68.1 |

± 4.83

In table SED vertical comp. = 10.15 SED horiz. comp. = 9.66

C ns V** CV ns

(ii) Fertilisation v. Variety

± 2.42

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 79.9 | 67.5 | 66.7 | 54.7 | 71.1 | 65.6 | 83.6 | 71.7 | 70.1 |
| Broadcast | 67.1 | 61.9 | 64.7 | 53.1 | 65.9 | 63.3 | 95.4 | 56.7 | 66.0 |
| Mean | 73.5 | 64.7 | 65.7 | 53.9 | 68.5 | 64.5 | 89.5 | 64.2 | 68.1 |

± 4.83

In table SED = 9.66

F ns V** FV ns

(iii) Fertilisation v. Cultivation

± 3.27

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 62.4 | 54.7 | 58.6 |
| Ploughed | 77.8 | 77.3 | 77.6 |
| Mean | 70.1 | 66.0 | 68.1 |

± 2.42

In table SED vertical comp. = 5.74 SED horiz. comp. = 4.83

F ns C ns FC ns

TABLE 3.11 SPECIES/CULTIVAR TRIAL 1976

Stem weight 15.8.76 (grammes per metre of crop row)

(i) Cultivation v. Species/Cultivar

± 6.5

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 53 | 39 | 60 | 63 | 67 | 59 | 107 | 48 | 62 |
| Ploughed | 57 | 63 | 86 | 81 | 74 | 81 | 123 | 56 | 78 |
| Mean | 55 | 51 | 73 | 72 | 71 | 70 | 115 | 52 | 70 |

± 3.2

In table SED vertical comp. = 11.0 SED horiz. comp. = 6.5

C ns V*** CV ns

(ii) Fertilisation v. Species/Cultivar

± 1.6

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 58 | 54 | 74 | 70 | 71 | 72 | 122 | 58 | 72 |
| Broadcast | 53 | 48 | 72 | 74 | 70 | 69 | 107 | 46 | 67 |
| Mean | 55 | 51 | 73 | 72 | 71 | 70 | 115 | 52 | 70 |

± 3.2

In table SED = 6.5

F* V*** FV ns

(iii) Fertilisation v. Cultivation

± 6.5

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 62 | 62 | 62 |
| Ploughed | 83 | 72 | 78 |
| Mean | 72 | 67 | 70 |

± 1.6

In table SED vertical comp. = 9.4 SED horiz. comp. = 3.2

F C ns FC* CFV*

TABLE 3.12 SPECIES/CULTIVAR TRIAL 1976

Weight of ears 15.8.76 (grammes per metre of crop row)

(i) Cultivation v. Species/Cultivar

± 7.4

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 83 | 72 | 79 | 93 | 93 | 89 | 80 | 86 | 84 |
| Ploughed | 83 | 93 | 98 | 94 | 92 | 105 | 90 | 94 | 94 |
| Mean | 83 | 82 | 88 | 94 | 93 | 97 | 85 | 90 | 89 |

± 3.9

In table SED vertical comp. = 12.8 SED horiz. comp. = 7.8

C ns V ns CV ns

(ii) Fertilisation v. Species/Cultivar

± 1.9

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 86 | 84 | 88 | 92 | 87 | 96 | 91 | 95 | 90 |
| Broadcast | 80 | 81 | 89 | 96 | 98 | 97 | 79 | 85 | 88 |
| Mean | 83 | 82 | 88 | 94 | 93 | 97 | 85 | 90 | 89 |

± 3.9

In table SED = 7.8

F ns V ns FV ns

(iii) Fertilisation v. Cultivation

± 7.4

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 82 | 86 | 84 |
| Ploughed | 97 | 90 | 94 |
| Mean | 90 | 88 | 89 |

± 1.9

In table SED vertical comp. = 10.9 SED horiz. comp. = 3.9

F ns C ns FC ns

TABLE 3.13 SPECIES/CULTIVAR TRIAL 1976
% nitrogen in shoot dry matter 28.5.76

(i) Cultivation v. Species/Cultivar

± 0.078

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 5.13 | 5.01 | 5.11 | 5.42 | 5.38 | 5.50 | 5.04 | 5.09 | 5.21 |
| Ploughed | 5.28 | 5.43 | 5.29 | 5.68 | 5.39 | 5.51 | 4.98 | 5.56 | 5.39 |
| Mean | 5.21 | 5.22 | 5.20 | 5.55 | 5.38 | 5.50 | 5.01 | 5.32 | 5.30 |

± 0.128

In table SED vertical comp. = 0.263 SED horiz. comp. = 0.256

C ns V ns CV ns

(ii) Fertilisation v. Species/Cultivar

± 0.064

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 5.26 | 5.17 | 5.22 | 5.61 | 5.49 | 5.38 | 4.58 | 5.19 | 5.24 |
| Broadcast | 5.15 | 5.27 | 5.19 | 5.48 | 5.27 | 5.63 | 5.44 | 5.44 | 5.36 |
| Mean | 5.21 | 5.22 | 5.20 | 5.55 | 5.38 | 5.50 | 5.01 | 5.32 | 5.30 |

± 0.128

In table SED = 0.256

F ns V ns FV ns

(iii) Fertilisation v. Cultivation

± 0.078

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 5.13 | 5.29 | 5.21 |
| Ploughed | 5.35 | 5.43 | 5.39 |
| Mean | 5.24 | 5.36 | 5.30 |

± 0.064

In table SED vertical comp. = 0.143 SED horiz. comp. = 0.128

F ns C ns FC ns

TABLE 3.14 SPECIES/CULTIVAR TRIAL 1976
% nitrogen in shoot dry matter 8.6.76

(i) Cultivation v. Species/Cultivar

± 0.099

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct drilled | 3.75 | 3.73 | 3.96 | 3.92 | 3.96 | 3.73 | 2.93 | 3.87 | 3.73 |
| Ploughed | 3.77 | 5.14 | 3.72 | 4.05 | 3.55 | 3.71 | 2.77 | 3.48 | 3.77 |
| Mean | 3.76 | 4.43 | 3.84 | 3.98 | 3.76 | 3.72 | 2.85 | 3.68 | 3.75 |

± 0.240

In table SED vertical comp. = 0.470 SED horiz. comp. = 0.479

C ns V** CV ns

(ii) Fertilisation v. Species/Cultivar

± 0.120

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 3.61 | 3.63 | 3.74 | 3.82 | 3.81 | 3.70 | 2.88 | 3.56 | 3.59 |
| Broadcast | 3.93 | 5.23 | 3.94 | 4.15 | 3.70 | 3.74 | 2.83 | 3.79 | 3.91 |
| Mean | 3.76 | 4.43 | 3.84 | 3.98 | 3.76 | 3.72 | 2.85 | 3.68 | 3.75 |

± 0.240

In table SED = 0.170

F ns V** FV ns

(iii) Fertilisation v. Cultivation

± 0.099

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 3.58 | 3.89 | 3.73 |
| Ploughed | 3.61 | 3.94 | 3.77 |
| Mean | 3.59 | 3.91 | 3.75 |

± 0.120

In table SED vertical comp. = 0.220 SED horiz. comp. = 0.240

F ns C ns FC ns

TABLE 3.15 SPECIES/CULTIVAR TRIAL 1976
% nitrogen in shoot dry matter 23.6.76

(i) Cultivation v. Species/Cultivar

± 0.033

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 1.71 | 2.06 | 2.44 | 2.46 | 2.20 | 2.43 | 1.62 | 1.87 | 2.10 |
| Ploughed | 1.89 | 1.82 | 1.86 | 2.42 | 1.92 | 1.99 | 1.91 | 2.07 | 1.99 |
| Mean | 1.80 | 1.94 | 2.15 | 2.44 | 2.06 | 2.21 | 1.77 | 1.97 | 2.04 |

± 0.091

In table SED vertical comp. = 0.177    SED horiz. comp. = 0.183

C ns    V***    CV*

(ii) Fertilisation v. Species/Cultivar

± 0.046

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 1.70 | 1.83 | 2.22 | 2.50 | 2.05 | 2.27 | 1.77 | 1.81 | 2.02 |
| Broadcast | 1.90 | 2.04 | 2.08 | 2.37 | 2.07 | 2.15 | 1.77 | 2.13 | 2.07 |
| Mean | 1.80 | 1.94 | 2.15 | 2.44 | 2.06 | 2.21 | 1.77 | 1.97 | 2.04 |

± 0.091

In table SED = 0.183

F ns    V***    FV ns

(iii) Fertilisation v. Cultivation

± 0.033

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 2.10 | 2.10 | 2.10 |
| Ploughed | 1.94 | 2.03 | 1.99 |
| Mean | 2.02 | 2.07 | 2.04 |

± 0.046

In table SED vertical comp. = 0.080    SED horiz. comp. = 0.091

F ns    C ns    FC ns

TABLE 3.16 SPECIES/CULTIVAR TRIAL 1976

Nitrogen uptake 28.5.76 (grammes per metre of crop row)

(i) Cultivation v. Species/Cultivar

± 0.019

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 0.42 | 0.31 | 0.29 | 0.31 | 0.36 | 0.38 | 0.61 | 0.33 | 0.38 |
| Ploughed | 0.47 | 0.50 | 0.59 | 0.48 | 0.58 | 0.59 | 0.96 | 0.73 | 0.61 |
| Mean | 0.45 | 0.41 | 0.44 | 0.40 | 0.47 | 0.49 | 0.78 | 0.53 | 0.50 |

± 0.036

In table SED vertical comp. = 0.073 SED horiz. comp. = 0.072

C ns V*** CV*

(ii) Fertilisation v. Species/Cultivar

± 0.018

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 0.59 | 0.46 | 0.49 | 0.48 | 0.50 | 0.50 | 0.69 | 0.60 | 0.54 |
| Broadcast | 0.30 | 0.37 | 0.39 | 0.31 | 0.43 | 0.47 | 0.88 | 0.46 | 0.45 |
| Mean | 0.45 | 0.41 | 0.44 | 0.40 | 0.47 | 0.49 | 0.78 | 0.53 | 0.50 |

± 0.036

In table SED = 0.072

F*** V*** FV**

(iii) Fertilisation v. Cultivation

± 0.019

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 0.41 | 0.34 | 0.38 |
| Ploughed | 0.66 | 0.56 | 0.61 |
| Mean | 0.54 | 0.45 | 0.50 |

± 0.018

In table SED vertical comp. = 0.037 SED horiz. comp. = 0.036

F*** C ns FC ns

TABLE 3.17 SPECIES CULTIVAR TRIAL 1976

Nitrogen uptake 8.6.76 (grammes per metre of crop row)

(i) Cultivation v. Species/Cultivar

± 0.109

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 0.64 | 0.67 | 0.68 | 0.49 | 0.87 | 0.56 | 0.95 | 0.89 | 0.72 |
| Ploughed | 1.20 | 1.15 | 1.01 | 0.83 | 1.05 | 0.96 | 1.30 | 1.07 | 1.07 |
| Mean | 0.92 | 0.91 | 0.85 | 0.66 | 0.96 | 0.76 | 1.13 | 0.98 | 0.89 |

± 0.070

In table SED vertical comp. = 0.131 SED horiz. comp. = 0.139

C* V** CV

(ii) Fertilisation v. Species/Cultivar

± 0.035

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 1.06 | 0.96 | 1.03 | 0.54 | 0.99 | 0.80 | 1.33 | 1.10 | 0.98 |
| Broadcast | 0.78 | 0.86 | 0.66 | 0.78 | 0.93 | 0.71 | 0.93 | 0.86 | 0.81 |
| Mean | 0.92 | 0.91 | 0.85 | 0.66 | 0.96 | 0.76 | 1.13 | 0.98 | 0.89 |

± 0.070

In table SED = 0.139

F*** V** FV ns

(iii) Fertilisation v. Cultivation

± 0.109

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 0.82 | 0.62 | 0.72 |
| Ploughed | 1.12 | 1.01 | 1.07 |
| Mean | 0.98 | 0.81 | 0.89 |

± 0.035

In table SED vertical comp. = 0.052 SED horiz. comp. = 0.070

F*** C* FC ns

TABLE 3.18 SPECIES/CULTIVAR TRIAL 1976

Nitrogen uptake 23.6.76 (grammes per metre of crop row)

(i) Cultivation v. Species/Cultivar

± 0.077

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Direct-drilled | 1.20 | 1.12 | 1.39 | 1.13 | 1.26 | 1.31 | 1.21 | 1.00 | 1.20 |
| Ploughed | 1.41 | 1.35 | 1.39 | 1.48 | 1.54 | 1.49 | 2.00 | 1.53 | 1.52 |
| Mean | 1.31 | 1.23 | 1.39 | 1.30 | 1.40 | 1.40 | 1.60 | 1.27 | 1.36 |

± 0.109

In table SED vertical comp. = 0.232 SED horiz. comp. = 0.219

C ns V ns CV ns

(ii) Fertilisation v. Species/Cultivar

± 0.055

| | Zephyr | Midas | Sirius | Sicco | Nelson | Leanda | Somro | Georgie | Mean |
|---|---|---|---|---|---|---|---|---|---|
| Combine-drilled | 1.36 | 1.23 | 1.46 | 1.37 | 1.45 | 1.43 | 1.49 | 1.31 | 1.39 |
| Broadcast | 1.26 | 1.23 | 1.32 | 1.24 | 1.35 | 1.36 | 1.72 | 1.23 | 1.34 |
| Mean | 1.31 | 1.23 | 1.39 | 1.30 | 1.40 | 1.40 | 1.60 | 1.27 | 1.36 |

± 0.109

In table SED = 0.219

F ns V ns FV ns

(iii) Fertilisation v. Cultivation

± 0.077

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 1.29 | 1.12 | 1.20 |
| Ploughed | 1.49 | 1.56 | 1.52 |
| Mean | 1.39 | 1.34 | 1.36 |

± 0.055

In table SED vertical comp. = 0.134 SED horiz. comp. = 0.109

F ns C ns FC ns

## 3.2 Spring Barley Cultivar Experiment (1976)

### 3.2.1 Grain Yield and its Components (Tables 3.19 to 3.22)

Mean grain yield was significantly greater under direct-drilling due to both the six row barley Clermont and the two row barley Georgie producing heavier grain yields under direct drilling. In contrast Maris Mink produced similar grain yields under both tillage treatments; although the cultivars responded differently to the tillage treatments the interaction was not significant. However the pre-harvest sampling of ear weights (Table 3.28) showed greater differential responses of cultivars to tillage and in this case the interaction was significant.

After combine-drilling of fertiliser all cultivars gave greater yields, although again the greater response was obtained with Clermont and Georgie. Although the interaction of tillage with fertiliser placement was not significant the best yield overall was obtained when the crop was grown under direct-drilling and combine-drilling of fertiliser.

Of the three yield components measured (number of ears, grains per ear and 1,000 grain weight) none can be used singly to explain the grain yield results. While Georgie had 12% fewer grains per ear under direct-drilling both Clermont and Maris Mink had similar numbers of grains per ear under both tillage systems (Table 3.20).

There was a significant interaction of tillage and fertiliser placement with respect to the number of grains per ear. After direct-drilling combine-drilling of fertiliser gave 6% more grains per ear, after ploughing the result was reversed and broadcast fertiliser application gave 14% more grains per ear. There were also large and significant cultivar differences in grains per ear due to the six row barley Clermont having more than twice as many grains per ear as the two row barleys Maris Mink and Georgie.

1,000 grain weights were slightly heavier under direct-drilling with broadcast fertiliser application. There was a significant difference in 1,000 grain weights of the cultivars, Georgie having a 16% heavier 1,000 grain weight than Clermont and Maris Mink (Table 3.22).

Despite Clermont producing more than twice as many grains per ear as Georgie and Mink its potential for outyielding the two row barleys was reduced by its production of 30% fewer ears than the two row barleys (Table 3.21).

3.2.2 Emergence and Growth (Tables 3.23 to 3.28)

On 23rd April there were significant cultivar differences in emergence (Table 3.23), Maris Mink having the least number of plants per metre of crop row and Clermont the highest. There were no cultivar interactions with the agronomic treatments, although there was a significant interaction between tillage and fertiliser placement. Under ploughing emergence was 9% greater when fertiliser was combine-drilled, but after direct-drilling emergence was 4% better after fertiliser was broadcast.

At anthesis there were significant differences in shoot dry matter production between cultivars and methods of fertilisation; there was also a significant interaction of cultivar with tillage (Table 3.24). Thus although Georgie produced 12% more dry matter than the other two cultivars under direct-drilling, after ploughing Clermont and Maris Mink respectively produced 35% and 8% more dry matter than Georgie. At anthesis Clermont was by far the most productive variety with a dry weight 27% greater than Georgie and 61% greater than Mink. At this stage all cultivars had produced more dry matter under combine-drilling of fertiliser.

Shoot counts made prior to harvest (Table 3.25) showed that Maris Mink and Georgie compensated for their having fewer plants at emergence by producing more tillers than Clermont. There were no significant differences in stem dry weight prior to harvest (Table 3.27) despite the highly significant ($P < 0.001$) differences in crop canopy height (Table 3.26). There were however significant differences in ear dry weight (see Section 3.2.1, Table 3.28).

3.2.3 Nitrogen Uptake (Tables 3.29 to 3.32)

At anthesis there were significant cultivar differences in the % of nitrogen in shoot dry matter (Table 3.29) and in nitrogen uptake (Table 3.30). There were no significant tillage or fertilisation effects although nitrogen uptake by all cultivars and under both tillage treatments was greater after fertiliser was combine-drilled.

At harvest significantly more nitrogen was taken up in the grain after fertiliser was combine-drilled and although the interaction of cultivation with fertiliser placement was not significant most nitrogen was taken up under a combination of minimum cultivation and combine-drilling of fertiliser (Table 3.32).

TABLE 3.19 BARLEY CULTIVAR TRIAL 1976

Grain yield at 15% moisture content (tonnes/ha) 11-19.8.76

(i) Cultivation v. Variety

± 0.048

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 6.11 | 5.17 | 5.73 | 5.67 |
| Ploughed | 5.67 | 5.16 | 5.44 | 5.42 |
| Mean | 5.89 | 5.17 | 5.59 | 5.55 |

± 0.098

In table SED vertical comp. = 0.17 SED horiz. comp. = 0.196

C* V*** CV ns

(ii) Fertiliser v. Variety

± 0.080

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 6.01 | 5.23 | 5.78 | 5.67 |
| Broadcast | 5.77 | 5.11 | 5.39 | 5.42 |
| Mean | 5.89 | 5.17 | 5.59 | 5.55 |

± 0.098

In table SED = 0.196

F* V*** FV ns

(iii) Cultivation v. Fertiliser

± 0.048

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 5.87 | 5.48 | 5.67 |
| Ploughed | 5.48 | 5.38 | 5.42 |
| Mean | 5.67 | 5.43 | 5.55 |

± 0.080

In table SED vertical comp. = 0.132 SED horiz. comp. = 0.160

C* F* CF ns

TABLE 3.20 BARLEY CULTIVAR TRIAL 1976

Number of grains per ear 4.8.76

(i) Cultivation v. Variety

± 0.78

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 39.6 | 17.7 | 17.7 | 25.0 |
| Ploughed | 39.8 | 17.5 | 20.1 | 25.8 |
| Mean | 39.7 | 17.6 | 18.9 | 25.4 |

± 0.96

In table SED vertical comp. = 1.92 SED horiz. comp. = 1.92

C ns V*** CV ns

(ii) Fertilisation v. Variety

± 0.78

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 39.2 | 17.3 | 18.1 | 24.9 |
| Broadcast | 40.2 | 17.9 | 19.6 | 25.9 |
| Mean | 39.7 | 17.6 | 18.9 | 25.4 |

± 0.96

In table SED = 1.92

F ns V*** FV ns

(iii) Cultivation v. Fertilisation

± 0.78

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 25.7 | 24.3 | 25.0 |
| Ploughed | 24.1 | 27.5 | 25.8 |
| Mean | 24.9 | 25.9 | 25.4 |

± 0.78

In table SED vertical comp. = 1.57 SED horiz. comp. = 1.56

C ns F ns CF*

TABLE 3.21 BARLEY CULTIVAR TRIAL 1976

Number of stems with ears per metre of crop row 4.8.76

(i) Cultivation v. Variety

± 3.5

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 74.5 | 103.5 | 117.5 | 98.5 |
| Ploughed | 78.2 | 116.0 | 110.5 | 101.6 |
| Mean | 76.4 | 109.7 | 114.0 | 100.0 |

± 4.3

In table SED vertical comp. = 8.58 SED horiz. comp. = 8.63

C ns V*** CV ns

(ii) Fertilisation v. Variety

± 3.5

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 72.9 | 110.4 | 114.0 | 99.1 |
| Broadcast | 79.9 | 109.1 | 114.0 | 101.0 |
| Mean | 76.4 | 109.7 | 114.0 | 100.0 |

± 4.3

In table SED = 8.63

F ns V*** FV ns

(iii) Fertilisation v. Cultivation

± 3.5

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 97.6 | 99.4 | 98.5 |
| Ploughed | 100.6 | 102.6 | 101.6 |
| Mean | 99.1 | 101.0 | 100.0 |

± 3.5

In table SED vertical comp. = 6.98 SED horiz. comp. = 7.05

F ns C ns FC ns

TABLE 3.22 BARLEY CULTIVAR TRIAL 1976

1,000 grain weights (g) 11-19.8.76

(i) Cultivation v. Variety

± 0.33

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 33.7 | 35.0 | 38.8 | 35.8 |
| Ploughed | 32.6 | 33.8 | 38.1 | 34.8 |
| Mean | 33.2 | 34.4 | 38.4 | 35.3 |

± 0.58

In table SED vertical comp. = 1.06 SED horiz. comp. = 1.16

C ns V*** CV ns

(ii) Fertilisation v. Variety

± 0.47

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 32.7 | 33.8 | 37.7 | 34.8 |
| Broadcast | 33.6 | 35.0 | 39.2 | 35.9 |
| Mean | 33.2 | 34.4 | 38.4 | 35.3 |

± 0.58

In table SED = 1.16

F ns V*** FV ns

(iii) Cultivation v. Fertilisation

± 0.33

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 35.2 | 36.4 | 35.8 |
| Ploughed | 34.3 | 35.4 | 34.8 |
| Mean | 34.8 | 35.9 | 35.3 |

± 0.47

In table SED vertical comp. = 0.82 SED horiz. comp. = 0.94

C ns F ns CF ns

TABLE 3.23 BARLEY CULTIVAR TRIAL 1976

Emergence 23.4.76 (plants per metre of crop row)

(i) Cultivation v. Variety

± 2.61

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 55.6 | 44.2 | 49.8 | 49.9 |
| Ploughed | 56.7 | 47.2 | 49.8 | 51.2 |
| Mean | 56.2 | 45.7 | 49.8 | 50.6 |

± 0.80

In table SED vertical comp. = 3.90 SED horiz. comp. = 1.53

C ns V*** CV ns

(ii) Fertilisation v. Variety

± 0.63

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 56.4 | 45.6 | 48.6 | 50.2 |
| Broadcast | 55.9 | 45.8 | 50.9 | 50.9 |
| Mean | 56.2 | 45.7 | 49.8 | 50.6 |

± 0.80

In table SED = 1.53

F ns V*** FV ns

(iii) Cultivation v. Fertilisation

± 2.61

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 48.0 | 51.8 | 49.9 |
| Ploughed | 52.5 | 49.8 | 51.2 |
| Mean | 50.2 | 50.9 | 50.6 |

± 0.63

In table SED vertical comp. = 3.80 SED horiz. comp. = 1.25

C ns F ns CF**

TABLE 3.24 BARLEY CULTIVAR TRIAL 1976

Shoot dry matter production at anthesis 14.6.76
(grammes per metre of crop row)

(i) Cultivation v. Variety

± 6.5

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 87.7 | 61.5 | 85.9 | 78.4 |
| Ploughed | 118.4 | 66.7 | 77.0 | 87.3 |
| Mean | 103.0 | 64.1 | 81.4 | 82.9 |

± 4.1

In table SED vertical comp. = 11.39    SED horiz. comp. = 8.27

C ns    V***    CV**

(ii) Fertilisation v. Variety

± 3.4

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 113.1 | 66.9 | 86.1 | 88.7 |
| Broadcast | 92.9 | 61.3 | 76.7 | 77.0 |
| Mean | 103.0 | 64.1 | 81.4 | 82.9 |

± 4.1

In table SED = 8.27

F*    V***    FV ns

(iii) Cultivation v. Fertilisation

± 6.5

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 81.2 | 75.5 | 78.4 |
| Ploughed | 96.2 | 78.4 | 87.3 |
| Mean | 88.7 | 77.0 | 82.9 |

± 3.4

In table SED vertical comp. = 10.34    SED horiz. comp. = 6.75

F*    C ns    FC ns

TABLE 3.25 BARLEY CULTIVAR TRIAL 1976

Number of stems per metre crop row 4.8.76

(i) Cultivation v. Cultivar

± 3.2

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 77 | 105 | 118 | 100 |
| Ploughed | 81 | 117 | 111 | 103 |
| Mean | 79 | 111 | 115 | 102 |

± 4.3

In table SED vertical comp. = 8.36　　SED horiz. comp. = 8.61

C ns　　V***　　CV ns

(ii) Fertilisation v. Cultivar

± 3.5

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 76 | 112 | 115 | 101 |
| Broadcast | 83 | 110 | 114 | 102 |
| Mean | 79 | 111 | 115 | 102 |

± 4.3

In table SED = 3.61

F ns　　V***　　FV ns

(iii) Cultivation v. Fertilisation

± 3.2

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 99 | 101 | 100 |
| Ploughed | 102 | 104 | 103 |
| Mean | 101 | 102 | 102 |

± 3.5

In table SED vertical comp. = 6.72　　SED horiz. comp. = 7.03

C ns　　F ns　　CF ns

TABLE 3.26 BARLEY CULTIVAR TRIAL 1976

Crop height (cm) 4.8.76

(i) Cultivation v. Cultivar

± 1.6

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 105 | 69 | 86 | 87 |
| Ploughed | 102 | 70 | 87 | 86 |
| Mean | 104 | 69 | 86 | 87 |

± 1.4

In table SED vertical comp. = 3.12 SED horiz. comp. = 2.69

C ns V*** CV ns

(ii) Fertilisation v. Cultivar

± 1.1

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 103 | 70 | 89 | 87 |
| Broadcast | 104 | 69 | 84 | 86 |
| Mean | 104 | 69 | 86 | 87 |

± 1.4

In table SED = 2.69

F ns V*** FV ns

(iii) Cultivation v. Fertilisation

± 1.6

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 89 | 85 | 87 |
| Ploughed | 86 | 86 | 86 |
| Mean | 87 | 86 | 87 |

± 1.1

In table SED vertical comp. = 2.71 SED horiz. comp. = 2.20

C ns F ns CF ns

TABLE 3.27 BARLEY CULTIVAR TRIAL 1976

Weight of stems 4.8.76
(grammes per metre of crop row)

(i) Cultivation v. Variety

± 6.2

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 86.4 | 79.3 | 84.7 | 83.5 |
| Ploughed | 86.9 | 87.9 | 84.3 | 86.4 |
| Mean | 86.7 | 83.6 | 84.5 | 84.9 |

± 4.4

In table SED vertical comp. = 11.39 SED horiz. comp. = 8.82

C ns V ns CV ns

(ii) Fertilisation v. Variety

± 3.6

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 86.3 | 83.8 | 82.6 | 84.2 |
| Broadcast | 87.0 | 83.4 | 86.3 | 85.6 |
| Mean | 86.7 | 83.6 | 84.5 | 84.9 |

± 4.4

In table SED = 8.82

F ns V ns FV ns

(iii) Cultivation v. Fertilisation

± 6.2

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 85.7 | 81.2 | 83.5 |
| Ploughed | 82.7 | 90.0 | 86.4 |
| Mean | 84.2 | 85.6 | 84.9 |

± 3.6

In table SED vertical comp. = 10.19 SED horiz. comp. = 7.20

C ns F ns CF ns

TABLE 3.28 BARLEY CULTIVAR TRIAL 1976

Weight of ears 4.8.76
(grammes per metre of crop row)

(i) Cultivation v. Variety

± 10.5

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 120.1 | 103.5 | 114.5 | 112.7 |
| Ploughed | 112.3 | 124.2 | 109.2 | 115.2 |
| Mean | 116.2 | 113.9 | 111.8 | 114.0 |

± 3.5

In table SED vertical comp. = 16.45    SED horiz. comp. = 8.63

C ns    V ns    CV*

(ii) Fertilisation v. Variety

± 4.3

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 111.7 | 110.9 | 112.7 | 111.7 |
| Broadcast | 120.7 | 116.8 | 111.0 | 116.2 |
| Mean | 116.2 | 113.9 | 111.8 | 114.0 |

± 3.5

In table SED = 8.63

F ns    V ns    FV ns

(iii) Cultivation v. Fertilisation

± 10.5

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 113.9 | 111.5 | 112.7 |
| Ploughed | 109.6 | 120.9 | 115.2 |
| Mean | 111.7 | 116.2 | 114.0 |

± 4.3

In table SED vertical comp. = 15.68    SED horiz. comp. = 7.04

C ns    F ns    CF ns

TABLE 3.29 BARLEY CULTIVAR TRIAL 1976

% N in shoot dry matter at anthesis 14.6.76

(i) Cultivation v. Cultivar

± 0.103

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 2.33 | 3.00 | 2.26 | 2.53 |
| Ploughed | 2.01 | 2.90 | 2.31 | 2.40 |
| Mean | 2.17 | 2.95 | 2.28 | 2.47 |

± 0.226

In table SED vertical comp. = 0.186 SED horiz. comp. = 0.143

C ns V*** CV ns

(ii) Fertilisation v. Cultivar

± 0.058

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 2.18 | 2.81 | 2.23 | 2.41 |
| Broadcast | 2.15 | 3.08 | 2.33 | 2.52 |
| Mean | 2.17 | 2.95 | 2.28 | 2.47 |

± 0.226

In table SED = 0.143

F ns V*** FV ns

(iii) Cultivation v. Fertilisation

± 0.103

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 2.45 | 2.60 | 2.53 |
| Ploughed | 2.36 | 2.44 | 2.40 |
| Mean | 2.41 | 2.52 | 2.47 |

± 0.167

In table SED vertical comp. = 0.167 SED horiz. comp. = 0.117

C ns F ns CF ns

TABLE 3.30 BARLEY CULTIVAR TRIAL 1976

Nitrogen uptake at anthesis 14.6.76
(grammes per metre of crop row)

(i) Cultivation v. Cultivar

± 0.102

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 2.03 | 1.84 | 1.93 | 1.93 |
| Ploughed | 2.38 | 1.87 | 1.75 | 2.00 |
| Mean | 2.21 | 1.86 | 1.84 | 1.97 |

± 0.101

In table SED vertical comp. = 0.219 SED horiz. comp. = 0.202

C ns V* CV ns

(ii) Fertilisation v. Cultivar

± 0.083

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 2.43 | 1.87 | 1.90 | 2.07 |
| Broadcast | 1.98 | 1.84 | 1.78 | 1.87 |
| Mean | 2.21 | 1.86 | 1.84 | 1.97 |

± 0.101

In table SED = 0.2021

F ns V* FV ns

(iii) Cultivation v. Fertilisation

± 0.102

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 1.95 | 1.91 | 1.93 |
| Ploughed | 2.18 | 1.82 | 2.00 |
| Mean | 2.07 | 1.87 | 1.97 |

± 0.083

In table SED vertical comp. = 0.186 SED horiz. comp. = 0.165

C ns F ns CF ns

TABLE 3.31 BARLEY CULTIVAR TRIAL 1976

% Nitrogen in grain dry matter

(i) Cultivation v. Cultivar

± 0.029

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 2.13 | 1.96 | 2.08 | 2.05 |
| Ploughed | 2.08 | 1.98 | 2.10 | 2.05 |
| Mean | 2.11 | 1.97 | 2.09 | 2.05 |

± 0.015

In table SED vertical comp. = 0.048 SED horiz. comp. = 0.031

C ns V*** CV ns

(ii) Fertilisation v. Cultivar

± 0.013

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 2.11 | 1.96 | 2.07 | 2.04 |
| Broadcast | 2.11 | 1.98 | 2.10 | 2.06 |
| Mean | 2.11 | 1.97 | 2.09 | 2.05 |

± 0.015

In table SED = 0.031

F ns V*** FV ns

(iii) Cultivation v. Fertilisation

± 0.029

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 2.05 | 2.06 | 2.05 |
| Ploughed | 2.03 | 2.07 | 2.05 |
| Mean | 2.04 | 2.06 | 2.05 |

± 0.013

In table SED vertical comp. = 0.045 SED horiz. comp. = 0.025

C ns F ns CF ns

TABLE 3.32 BARLEY CULTIVAR TRIAL 1976

Nitrogen uptake by grain (kg/ha)

(i) Cultivation v. Cultivar

± 0.81

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 109.6 | 83.2 | 98.3 | 97.0 |
| Ploughed | 100.5 | 86.7 | 97.0 | 94.7 |
| Mean | 105.0 | 84.9 | 97.6 | 95.9 |

± 2.21

In table SED vertical comp. = 3.79 SED horiz. comp. = 4.42

C ns V*** CV ns

(ii) Fertilisation v. Cultivar

± 1.80

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 106.9 | 84.4 | 100.2 | 97.2 |
| Broadcast | 103.1 | 85.5 | 95.0 | 94.6 |
| Mean | 105.0 | 84.9 | 97.6 | 95.9 |

± 2.21

In table SED = 4.42

F ns V*** FV ns

(iii) Cultivation v. Fertilisation

± 0.81

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 99.6 | 94.4 | 97.0 |
| Ploughed | 94.8 | 94.7 | 94.7 |
| Mean | 97.2 | 94.6 | 95.9 |

± 1.80

In table SED vertical comp. = 2.80 SED horiz. comp. = 3.61

C ns F ns CF ns

## 3.3 Spring Barley Cultivar Experiment (1977)

### 3.3.1 Grain Yield (Table 3.33)

In contrast to 1976 (Table 3.19) all cultivars yielded more, although not significantly, under ploughing. The greatest yield was produced by Maris Mink and not Clermont as in 1976; the relatively low yield of Clermont was probably due to its shedding grain during a week of strong winds prior to harvest. As in 1976 combine drilling of fertiliser had a beneficial effect on crop yield, although the effect was greater in 1977; overall combine drilling resulted in a 6% greater yield. In 1976 and 1977 Georgie showed the greatest response to combine drilling producing a 7% heavier grain yield than after broadcasting.

### 3.3.2 Crop Growth (Tables 3.34 to 3.35)

Plant counts made on the 13th May showed no significant effects of any treatment on plant population. At anthesis there were also no significant treatment effects on shoot dry matter production. Overall shoot dry matter production was lower under direct drilling than under ploughing and was 19% greater after combine drilling rather than broadcast application of seedbed fertiliser.

TABLE 3.33 BARLEY CULTIVAR TRIAL 1977

Grain yield at 15% moisture content (tonnes/ha) 5.9.77

(i) Cultivation v. Cultivar

± 0.141

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 4.97 | 5.99 | 5.68 | 5.55 |
| Ploughed | 5.47 | 6.64 | 6.32 | 6.14 |
| Mean | 5.22 | 6.32 | 6.00 | 5.85 |

± 0.088

In table SED vertical comp. = 0.246 SED horiz. comp. = 0.175

C ns V*** CV ns

(ii) Fertilisation v. Cultivar

± 0.072

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 5.36 | 6.46 | 6.20 | 6.01 |
| Broadcast | 5.07 | 6.17 | 5.80 | 5.68 |
| Mean | 5.22 | 6.32 | 6.00 | 5.85 |

± 0.088

In table SED = 0.175

F** V*** FV ns

(iii) Cultivation v. Fertilisation

± 0.088

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 5.70 | 5.40 | 5.55 |
| Ploughed | 6.32 | 5.97 | 6.14 |
| Mean | 6.01 | 5.68 | 5.85 |

± 0.072

In table SED vertical comp. = 0.143 SED horiz. comp. = 0.223

C ns F** CF ns

TABLE 3.34 BARLEY CULTIVAR TRIAL 1977

Number of plants/$m^2$ 13.5.77

(i) Cultivation v. Cultivar

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 398 | 366 | 355 | 373 |
| Ploughed | 410 | 401 | 379 | 397 |
| Mean | 404 | 384 | 367 | 385 |

In table SED vertical comp. = 37.3 SED horiz. comp. = 29.7

C ns V ns CV ns

(ii) Fertilisation v. Cultivar

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 410 | 395 | 356 | 387 |
| Broadcast | 398 | 372 | 379 | 383 |
| Mean | 404 | 384 | 367 | 385 |

In table SED = 29.7

F ns V ns FV ns

(iii) Cultivation v. Fertilisation

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 373 | 373 | 373 |
| Ploughed | 401 | 393 | 397 |
| Mean | 387 | 383 | 385 |

In table SED vertical comp. = 24.3 SED horiz. comp. = 33.1

C ns F ns CF ns

TABLE 3.35 BARLEY CULTIVAR TRIAL 1977

Shoot dry weight $g/m^2$ 4.7.77

(i) Cultivation v. Cultivar

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Direct-drilled | 451 | 511 | 480 | 481 |
| Ploughed | 515 | 545 | 433 | 498 |
| Mean | 483 | 528 | 457 | 489 |

In table SED vertical comp. = 58.4 SED horiz. comp. = 60.9

C ns V ns CV ns

(ii) Fertilisation v. Cultivar

| | Clermont | Maris Mink | Georgie | Mean |
|---|---|---|---|---|
| Combine-drilled | 549 | 540 | 506 | 532 |
| Broadcast | 417 | 517 | 407 | 447 |
| Mean | 483 | 528 | 457 | 489 |

In table SED = 60.9

F ns V ns FV ns

(iii) Cultivation v. Fertilisation

| | Combine-drilled | Broadcast | Mean |
|---|---|---|---|
| Direct-drilled | 515 | 447 | 481 |
| Ploughed | 549 | 447 | 498 |
| Mean | 532 | 447 | 489 |

In table SED vertical comp. = 46.7 SED horiz. comp. = 49.8

C ns F ns CF ns

## 3.4 Winter Wheat Cultivar Experiment 1975-76

### 3.4.1 Grain Yield (Table 3.36)

There was a significant cultivar difference in grain yield with Mega yielding 8% more than Maris Widgeon and 13% more than Maris Fundin. This difference in yield was accompanied by a significant cultivar/tillage interaction as although Fundin produced a greater yield under direct drilling Mega and Widgeon had greater yields under ploughing. The method of fertilisation (split or single application of nitrogen) had a negligible effect on grain yield.

### 3.4.2 Emergence and Crop Height (Tables 3.37 and 3.38)

There were no significant effects of tillage or method of fertilisation on emergence although there were marked cultivar differences, Maris Fundin having 13% fewer plants than Mega or Maris Widgeon.

The only significant differences in crop height were the cultivar differences.

TABLE 3.36 WHEAT CULTIVAR TRIAL 1976

Grain yield at 15% moisture content (tonnes/ha) 19.8.76

(i) Cultivation v. Variety

± 0.159

| | Maris Fundin | Mega | Maris Widgeon | Mean |
|---|---|---|---|---|
| Direct-drilled | 4.39 | 4.56 | 4.17 | 4.37 |
| Ploughed | 3.84 | 4.73 | 4.45 | 4.35 |
| Mean | 4.11 | 4.66 | 4.31 | 4.36 |

± 0.093

In table SED vertical comp. = 0.270 SED horiz. comp. = 0.19

C ns V** CV*

(ii) Fertilisation v. Variety

± 0.076

| | Maris Fundin | Mega | Maris Widgeon | Mean |
|---|---|---|---|---|
| Split Application | 4.20 | 4.56 | 4.39 | 4.38 |
| Single Application | 4.03 | 4.77 | 4.23 | 4.34 |
| Mean | 4.11 | 4.66 | 4.31 | 4.36 |

± 0.093

In table SED = 0.19

F ns V** FV ns

(iii) Fertilisation v. Cultivation

± 0.159

| | Split Application | Single Application | Mean |
|---|---|---|---|
| Direct-drilled | 4.45 | 4.30 | 4.37 |
| Ploughed | 4.32 | 4.39 | 4.35 |
| Mean | 4.38 | 4.34 | 4.36 |

± 0.076

In table SED vertical comp. = 0.25 SED horiz. comp. = 0.15

F ns C ns FC ns

TABLE 3.37 WHEAT CULTIVAR TRIAL 1976

Emergence 12.12.75
(number of plants per metre of crop row)

(i) Cultivation v. Variety

± 1.06

| | Maris Fundin | Mega | Maris Widgeon | Mean |
|---|---|---|---|---|
| Direct-drilled | 48.0 | 55.1 | 56.2 | 53.1 |
| Ploughed | 48.3 | 55.3 | 53.7 | 52.4 |
| Mean | 48.2 | 55.2 | 55.0 | 52.8 |

± 1.21

In table SED vertical comp. = 2.47 SED horiz. comp. = 2.41

C ns V*** CV ns

(ii) Fertilisation v. Variety

± 0.98

| | Maris Fundin | Mega | Maris Widgeon | Mean |
|---|---|---|---|---|
| Split Application | 49.1 | 54.0 | 54.6 | 52.6 |
| Single Application | 47.2 | 56.4 | 55.3 | 53.0 |
| Mean | 48.2 | 55.2 | 55.0 | 52.8 |

± 1.21

In table SED = 2.41

F ns V*** FV ns

(iii) Cultivation v. Fertilisation

± 1.06

| | Split Application | Single Application | Mean |
|---|---|---|---|
| Direct-drilled | 52.6 | 53.6 | 53.1 |
| Ploughed | 52.5 | 52.4 | 52.4 |
| Mean | 52.6 | 53.0 | 52.8 |

± 0.98

In table SED vertical comp. = 2.04 SED horiz. comp. = 1.97

C ns F ns CF ns

TABLE 3.38 WHEAT CULTIVAR TRIAL 1976

Crop canopy height (cm) 18.8.76

(i) Cultivation v. Variety

± 0.6

| | Maris Fundin | Mega | Maris Widgeon | Mean |
|---|---|---|---|---|
| Direct-drilled | 89.2 | 95.0 | 101.8 | 95.3 |
| Ploughed | 86.3 | 87.0 | 106.8 | 93.4 |
| Mean | 87.7 | 91.0 | 104.3 | 94.4 |

± 3.3

In table SED vertical comp. = 5.51 SED horiz. comp. = 6.66

C ns V** CV ns

(ii) Fertilisation v. Variety

± 2.7

| | Maris Fundin | Mega | Maris Widgeon | Mean |
|---|---|---|---|---|
| Split Application | 85.8 | 90.2 | 100.3 | 92.1 |
| Single Application | 89.7 | 91.8 | 108.3 | 96.6 |
| Mean | 87.7 | 91.0 | 104.3 | 94.4 |

± 3.3

In table SED = 6.66

F ns V** FV ns

(iii) Cultivation v. Fertilisation

± 0.6

| | Split Application | Single Application | Mean |
|---|---|---|---|
| Direct-drilled | 91.9 | 98.8 | 95.3 |
| Ploughed | 92.3 | 94.4 | 93.4 |
| Mean | 92.1 | 96.6 | 94.4 |

± 2.7

In table SED vertical comp. = 3.95 SED horiz. comp. = 5.44

C ns F ns CF ns

CFV***

# PART I

# FIELD EXPERIMENTS

## SECTION 4

## DISCUSSION

# 4. DISCUSSION

## 4.1 The Effects of the Method of Cultivation on Crop Growth and Yield

The first observation which can be made when bringing together the results of the four experiments is that they illustrate the range of responses which may be found when studying crop responses to tillage. In the winter wheat experiment presence or absence of cultivation had little effect on yield. In two of the spring cereal experiments yield was reduced under direct drilling although in the spring barley cultivar experiment in 1976 overall yield was greater after direct drilling.

This pattern of results matched those reported by other workers in suggesting that spring cereals may be more sensitive to the changed soil conditions found under direct drilling than winter wheat. Cannell et al (1978) in a review of the suitability of soils for sequential direct drilling of combine-harvested crops reported that when soil physical conditions restrict crop growth, spring sown cereals are more at risk in direct-drilled land than winter cereals. They suggested that this is probably because of the shorter period in which spring crops are able to develop adequate root systems, thus if root growth is initially restricted there is relatively little time available for compensatory growth. This hypothesis is supported by the work of Biscoe and Gallagher (1978) who found (in studies of the growth of winter wheat and spring barley at the same site in subsequent years) that at the start of rapid crop growth winter wheat roots had reached a depth of 120 cm whereas those of barley had only descended to 50 cm.

An explanation of the varied responses, to the different cultivation systems, found in each experiment can be postulated after referring to the observations on the aerial and edaphic environments found at each site during the experiments.

In 1976 at Clifton Mains Farm the weather records (Table 2.9) suggest that the spring barley crop may have been experiencing water shortages from early in its growth as estimated potential evapotranspiration exceeded rainfall from April to August. Although the winter wheat crop growing in the same field would have been suffering similar deficits the work of Biscoe and Gallagher (1978) suggests that the wheat root system would have been relatively well developed at the onset of water deficits and so better able to tap the available soil water reserves than the developing root system of the spring barley crop. Thus by inference the spring barley crop would have been more sensitive to any modification in the supply of soil water in the upper soil horizons.

The greater yield after direct drilling spring barley cultivars at Clifton Mains was found despite the poorer growth of the direct-drilled crop at anthesis. An explanation for these apparently contradictory results can be advanced after reference to two observations which have frequently been made in experiments comparing ploughing with direct drilling:-

1. The water content of soil after direct drilling is often higher than after ploughing (see Section 1). The work of Goss and Howse (1977) is of particular relevance; they found that in the dry conditions of 1976 the water content of direct-drilled soil was higher than in similar ploughed clay soil.
2. Under direct drilling early crop growth is frequently retarded (see Section 1). When soil water content is below field capacity, loss of water below 30 cm occurs largely by root uptake (Long and French 1967), furthermore the amount of water taken up may be largely determined by rooting density (Ehlers 1976, 1980). Thus an early retardation of root growth in compact soil may have led to moisture conservation. Indeed Passioura (1977), when discussing strategies by which wheat yield may be maximised when water supply is limiting, suggested that if the rate of water extraction from the subsoil was slowed down the amount of available soil water at anthesis would be increased and this should increase yield.

Thus both of the above mentioned factors could have led to increased water availability on direct-drilled plots during the crucial grain filling period. The smaller 1,000 grain weight of the crop from ploughed plots lends support to this hypothesis because it has been found that although grain weight is relatively stable it can be reduced by drought during the grain filling period (Aspinall 1965).

In the two other spring cereal experiments (Species/Cultivars 1976, Spring Barley Cultivars 1977) it was found that the yield under direct drilling was less than under ploughing although in both experiments the effect was not statistically significant.

On the Species/Cultivars experiment in Hay Knowes field the plant population at emergence was lower on direct-drilled than ploughed plots. Field observations had shown that plants on direct-drilled plots were yellow and weakened. At this site a poor straw burn after harvest meant that crop residues were present on the surface of direct-drilled plots during sowing. The symptoms displayed by the emerging direct-drilled crop may have been caused by several factors in particular:-

1. Damage from herbicide residues left on crop debris (Bakermans and de Wit 1970).
2. Incorporation of crop residues into the seeding slits during direct drilling. The subsequent decomposition of these residues may lead to the production of toxins harmful to the germinating seedlings (Ellis 1979).

No experimental evidence is available to determine which of these hypotheses may be most appropriate in this case, although as the crop was drilled in relatively wet conditions which favour the production of toxins by decomposing straw (Ellis 1979) then some support is given to the second hypothesis.

Crop growth continued to be poorer on the direct-drilled plots and at the time of the first shoot sample, on 14th May 1976, shoot dry weight was markedly lower on direct-drilled plots. This difference in crop dry matter production between cultivation treatments increased during May; then as the crop developed, compensatory growth by the direct-drilled crop reduced the magnitude of the difference so that just before harvest the shoot dry weight on direct-drilled plots was 85% of that under ploughing (see Table 4.1).

TABLE 4.1 SPRING CEREAL SPECIES/CULTIVARS TRIAL

Change in crop dry weight under contrasting cultivation treatments

| Date | Mean crop dry weight under ploughing (grammes per metre of crop row) | Mean crop dry weight Direct drilling as % ploughing | Statistical significance of difference |
|---|---|---|---|
| 14.5.76 | 1.94 | 71% | ns |
| 18.5.76 | 11.58 | 63% | * |
| 8.6.76 | 30.43 | 65% | * |
| 23.6.76 | 77.6 | 76% | ns |
| 15.8.76 | 172.0 | 85% | - |

Analysis of the nitrogen content of shoot samples from the species/cultivar trial showed that nitrogen uptake was reduced under direct drilling particularly at the early stages of growth. As the percentage nitrogen content of shoots was not significantly affected by the cultivation treatments the differences in nitrogen uptake largely reflected treatment differences in dry matter production. Holmes (1976) reported similar reductions in nitrogen uptake under direct drilling in a long term cultivation experiment near the site of the species/cultivar trial on a similar soil of the Macmerry Soil Series, (Soil Survey of Scotland), and other workers have reported similar effects (see Section 1). Baldwin (1975) concluded that the uptake of nitrate, which is relatively mobile in soil, is related to its concentration in the rooting volume and the size of the rooting volume. Thus soil properties which influence root growth may have as much importance as soil chemical composition in determining the uptake of nitrate. Under direct drilling root growth may be restricted, particularly during early growth (see Section 1), and nitrogen mineralisation may also be reduced (Phillips et al 1980) although this effect may be only evident during winter and spring (Dowdell and Cannell 1975). Both these factors may have served to limit nitrogen uptake on the species/cultivar trial particularly in the early phases of growth. As crop dry matter production is frequently a function of the supply of nutrients (Milthorpe and Moorby 1979) the reduction in dry matter accumulation under direct drilling on the species/cultivar trial may be a result of the limitation to nitrogen uptake.

Despite the compensatory growth of the direct-drilled crop in the species/cultivar trial grain yield was reduced by 13% under direct drilling; this yield reduction was associated with a reduction in the numbers of ears and of grains per ear.

The potential yield of cereals is determined during the early stages of inflorescence differentiation by the number of tillers which form inflorescences and the number of spikelets (and florets) formed per inflorescence (Milthorpe and Moorby 1979). The rate of production and maximum number of ear bearing shoots produced by a cereal cultivar is markedly influenced by the supply of substrates, particularly nitrogen (Milthorpe and Moorby 1979). Thus the observed limitations to nitrogen uptake under direct drilling in the species/cultivar trial in addition to reducing crop dry matter production may have diminished the production and survival of ear bearing shoots and so led to the observed reduction in ear number under direct drilling. The reduction in the number of grains per ear may have arisen from effects on either spikelet production or survival. Spikelet differentiation appears to stop when stamens are differentiated in the most advanced floret; thus the greatest number of spikelets are formed when the rate of spikelet differentiation exceeds the rate of growth of the youngest spikelet (Milthorpe and Moorby 1979). Considerable differences have been found in both the rate and duration of spikelet initiation but the reasons for these differences are not known (Gallagher et al 1976). Further regulation of spikelet number may be caused by the death of up to 40% of spikelets in the period from ear emergence to anthesis (Gallagher and Biscoe 1978).

## 4.2 The Effect of the Method of Fertiliser Application on Crop Growth and Yield

### 4.2.1 Split Versus Single Application of Nitrogen to Winter Wheat

The method of nitrogen application had no significant effect on winter wheat emergence and grain yield. This lack of response to the timing of nitrogen application was probably due to the low over-winter rainfall; from October 1975 to February 1976 only 129 mm of rain fell, less than half the long term average for this period. The volume of rain is a crucial factor moderating the availability of applied nitrogen and its subsequent use by cereals (Cooke 1972). It has been found in experiments in the Netherlands (van der Paauw 1962) and in Britain (Devine and Holmes 1964) that the greater the winter rainfall the greater the amount of nitrogen leached from the soil and consequently the greater the need of the crop for nitrogen in the spring (Russell 1973). So the lack of response to timing of nitrogen application may have been atypical and further experiments may be needed to explore the interaction with method of cultivation or winter wheat cultivar.

4.2.2 Method of Fertiliser Placement for Spring Cereals

In all trials spring cereals produced heavier grain yields when fertiliser was combine-drilled with the seed rather than broadcast. In both the species/cultivar and spring barley cultivar trials in 1976 the greater yield after combine-drilling was associated with an increase in 1,000 grain weight, although the effect of combine-drilling on this and other components of yield were small and not statistically significant.

Although combine-drilling placed fertiliser in close proximity to the seed, plant population at emergence was not affected and the differences in crop growth between the fertiliser placement treatments appeared to develop after crop establishment, the largest effects being on the production of crop dry matter. On the species/cultivar trial crop dry weight was consistently higher under combine-drilling. The greatest treatment differences in crop dry weight were found early in the season when the rate of crop dry matter production was at its peak (Table 4.2).

TABLE 4.2. SPRING CEREAL SPECIES/CULTIVAR TRIAL

Change in crop dry weight under contrasting fertiliser placement treatments

| | Mean crop dry weight after combine-drilling (grammes per metre of crop row) | Mean crop dry weight Broadcasting as % of combine-drilling | Statistical significance of difference |
|---|---|---|---|
| 14.5.76 | 1.7 | 90% | * |
| 28.5.76 | 10.4 | 81% | *** |
| 8.6.76 | 27.8 | 80% | *** |
| 23.6.76 | 70.1 | 94% | ns |
| 15.8.76 | 162 | 96% | - |

When planning these experiments a test of different methods of fertiliser placement were included to see if combine-drilling could increase the uptake of applied nitrogen to benefit crop growth and yield. In the species/cultivar and the spring barley cultivar trials in 1976 nitrogen uptake was greater under combine-drilling. In the species/cultivar trial nitrogen uptake under combine-drilling was particularly enhanced relative to broadcasting during early growth. This pattern of nitrogen uptake seems to be closely associated with changes in crop dry weight. As was previously discussed (Section 4.1) the uptake of nitrate by plants is related to its concentration in the rooting volume and the size of the rooting volume. Thus combine-drilling may particularly facilitate nitrogen uptake by a young crop because the nitrogen source is close to the seed and so nitrate concentration within the limited volume of the developing root system may be greater than after broadcasting of fertiliser. As the crop develops and the volume of soil explored by the roots increases then the overall concentration of nitrate throughout the rooting volume may be similar under both fertilisation treatments. Thus the size of treatment differences in nitrogen uptake and consequently plant dry weight are reduced and may in some years disappear altogether as the crop proceeds towards maturity.

Other workers studying the effect of fertiliser placement have also demonstrated that combine drilling may lead to more efficient fertiliser usage by the crop (Cooke 1972). Toews and Soper (1978) found that when 22.4 or 44.8 kg of N/ha as ammonium nitrate was combine-drilled yields of barley were higher than when the same amount of fertiliser was broadcast. They too attributed the increased yield to increased availability in the early stages of crop growth of nitrogen applied in a band near the seed. However, at higher rates of fertiliser application this increased availability may be a disadvantage as high concentrations of mineral ions in the soil solution may adversely affect root and consequently plant growth. Pollard and Elliott (1978) after drilling 102 kg N/ha with seed of barley found that emergence was delayed and crop growth was initially slower under combine drilling than broadcasting.

In the spring cereal trials the seedbed fertiliser was a compound of nitrogen, phosphate and potassium. The differences in crop growth between the methods of fertiliser placement may have been due in part to treatment differences in the uptake of phosphate and potassium. Phosphate and potassium diffuse slowly through soil and usually only travel a few millimetre to root surfaces (Cannell and Drew 1973, Baldwin 1975). Thus the placement of fertiliser in close proximity to the developing root system, in combine drilling, may be expected to facilitate uptake of potassium and phosphate and so improve yields. The improved availability of potassium and phosphate to the developing crop may be particularly beneficial as the major part of the uptake of these nutrients occurs at a relatively early growth stage (Williams 1955). It has been shown that an improvement in supply of phosphate and potassium can also improve the crop response to nitrogen (E.W. Russell 1973, p.55). Thus the greater crop growth found after combine-drilling may be attributable to greater uptake of phosphate and potassium as well as nitrogen.

## 4.3 Interaction of Cultivation with Method of Fertiliser Application

After direct drilling the uptake of nitrogen by both spring barley (Holmes 1976) and winter cereals (Cannell and Ellis 1979) may be reduced and greater applications of fertiliser nitrogen are needed to produce the same yields as under ploughing. This reduction in nitrogen uptake under direct drilling may be attributed to:-

1. Inhibition of root growth under direct drilling because of mechanical impedance in compact soil; this leads to slower uptake of nitrogen as the soil volume explored by roots will be reduced (Holmes 1976).
2. Reduction in nitrogen mineralisation and an increase in denitrification in direct-drilled soil leading to a reduction in available nitrogen (Dowdell and Cannell 1975).

Holmes (1976) suggested that the demand for nitrogen by a direct-drilled crop (which appears to be particularly acute in early growth) could be met by combine drilling fertiliser with seed.

This hypothesis was tested in three of the four trials made. It was found that although nitrogen uptake and grain yields were greater after combine drilling of a compound fertiliser this effect did not interact with the cultivation treatments. Thus the environmental conditions at each site determined which cultivation treatment produced the heaviest grain yields (Section 4.2.2); although combine drilling always increased yields overall it did not significantly affect the relative difference in yield between cultivation treatments. As noted in Section 4.2.1 the results from the winter wheat cultivar trial were inconclusive.

## 4.4 Interaction of Cereal Species and Cultivars with Cultivation

These experiments were designed to establish whether commercially available cereal varieties differed in their suitability for use in a direct drilling system. The cultivars used in the experiments were selected for their diversity, particular attention being given to differences in crop height as a review of literature suggested that dwarf cultivars may be less suited to the soil conditions produced by direct drilling (see Section 1.4).

The spring cereal experiments gave few indications of significant variety/cultivation interactions. There was a significant variety/ cultivation interaction with respect to emergence in the species/cultivar trial in 1976. The emergence of all varieties were poorer under direct drilling although the emergence of the oat and rye varieties was particularly reduced, these differences did not affect yield potential as by harvest the oat and rye varieties had similar ear populations under both cultivation treatments. Variety/cultivation interactions were also found in shoot dry matter production in both the spring barley cultivars trial and the species/ cultivar trial in 1976, however these effects were transient. The winter wheat trial at Clifton Mains Farm was the only experiment in which there was a significant variety/cultivation interaction with respect to grain yield. The yield of the semi-dwarf variety Maris Fundin was greatest after direct drilling, whereas the yields of Mega and Maris Widgeon were greatest after ploughing, although the overall mean yield of Fundin was unexpectedly lower than that of the older and taller cultivars Mega and Widgeon. The relatively poor yield of Fundin may have been due to drought in 1976 (see Section 4.1) as field experience suggests Fundin to be relatively susceptible to water stress (Holmes 1978, personal communication). Briggle and Vogel (1968) reported that under adverse conditions, particularly drought, semi-dwarf cultivars may be outyielded by taller cultivars. They suggested this was partly associated with poor coleoptile development but might also be an indication of limited root development by semi-dwarf cultivars. In a previous section it was suggested that the greater yield after direct drilling spring barley cultivars at Clifton Mains was due to greater water availability on direct drilled plots. Thus if Fundin is relatively susceptible to water stress it could be similarly argued that its relatively greater yield under direct drilling was due to greater water availability on direct drilled plots.

# PART II

# LABORATORY EXPERIMENTS

## SECTION 5

## REVIEW: GENETIC VARIATION IN ROOT SYSTEMS

# 5. REVIEW: GENETIC VARIATION IN ROOT SYSTEMS

## 5.1 Evidence of Genetic Variation

The fibrous root system of temperate cereals has two distinct components, the seminal (seedling) roots and nodal (adventitious, secondary, crown) roots. The seminal roots develop from primordia within the seed, the nodal roots develop adventitiously from the lower nodes of stem.

There is evidence of genetic variation in many characters of both the seminal and nodal root systems. Studies have been made of the variation in root number in a number of cereal species. Pope (1945) studied seminal root production in seedlings of 72 varieties of barley and found varietal differences in seminal root number. The number of seminal roots ranged from 5.4 in the six-rowed variety Club to 8.9 in the two-rowed varieties Alpha and White Smyrna. Pope (1945) suggested that seminal root number is a varietal character as he observed that the number of roots produced by individual seeds of a variety seldom varied by more than two from the variety mean. More recently similar studies have been made of the number of seminal roots produced by wheat genotypes. Tomasovic (1978) found significant differences in seminal root number among 40 wheat genotypes and reported that seminal root number ranged from 3.30 in the variety Centurk to 5.70 in the variety Vigorka. In a comprehensive study Robertson, Waines and Gill (1979) surveyed the numbers of seminal roots produced by seedlings of 143 wild and domesticated wheat genotypes. They also found a significant variation in the numbers of seminal roots produced by different wheat genotypes; root numbers ranged from 2.50 in a <u>Triticum araraticum</u> genotype to 6.45 in a genotype of <u>Triticum turgidum</u> var <u>durum</u>. Robertson, Waines and Gill (1979) concluded that seminal root number was genetically controlled as the number of seminal roots produced by a variety was found to be stable between environments and from one generation to the next.

Variation in other root characters is less well studied, although there is evidence of genotypic variation in root weight, length and diameter. Donald (1979) compared the growth of uniculm and tillered barley varieties. He found that although tillered and uniculm lines had similar shoot dry weight, the uniculm line had a 66% greater root weight.

Pinthus and Eshel (1962) studied the root development of wheat varieties in glasshouse experiments and found significant differences in the seminal root length of seedlings of several wheat varieties. A study of the root growth of wheat genotypes was made by O'Brien (1979). He found significant varietal differences in lateral and nodal root length among 10 wheat genotypes. He also found varietal differences in the numbers of first and second order lateral roots.

Some studies have been made of varietal differences in root diameter in relation to varietal differences in resistance to lodging. Derick and Hamilton (1942) found varietal differences in the numbers and thickness of nodal roots of oats; varieties with more and thicker roots were found to be more resistant to lodging. Jezowski (1978) reported a similar study of the factors determining lodging resistance in spring barley. He found varietal differences in diameter and angle of penetration of seminal roots and suggested that the angle of root penetration was the most important character determining lodging resistance in the varieties surveyed.

In the studies reviewed above evidence of genotypic variation in root growth comes from comparisons made between fixed genotypes. In order to examine the mechanism of genetic control of root growth it is necessary to make crosses between different genotypes and examine the root characters of the segregating populations. Few such studies have been made. Monyo and Whittington (1970) examined the growth characteristics of root systems in the wheat varieties Chinese Spring and Hope and the chromosome substitution lines of Hope into Chinese Spring. They found that the genetic control of root growth was largely additive in nature and concluded that variation in root characteristics were influenced by single genes affecting the duration of vegetative growth as well as by polygenic systems. Surma et al (1978) made a study of the genetic control of certain root morphological characters in spring barley. They examined the root morphological characters of five varieties of barley (Antalek, Alsa, Cebeco 7161, Lubiski and Union) and their $F_1$ and $F_2$ hydrids. They found that root weight, volume and surface area were largely determined by additive genes although there were also indications of some influence of dominant or epistatic genes.

Monyo and Whittington (1970) and Surma et al (1978) suggested that as the control of root characters was largely by additive genetic systems progress in breeding should be facilitated. The additive portion of phenotypic variance is of greater importance in the resemblance between relatives than the dominant portion (Strickberger 1968).

## 5.2 The Significance of Genetic Variation

The main significance of genetic variation in root growth at present lies in breeding crops able to withstand adverse environmental conditions. Examples of how genetic variation in root growth may allow selection of genotypes able to withstand environmental stresses such as drought, nutrient deficiency and soil compaction are reviewed in the following paragraphs.

In many parts of the world an insufficient supply of water is often the main factor limiting crop production. It has been estimated that cropping is impossible without irrigation on some 10% of land which is otherwise suitable for agriculture and yields are restricted by water stress on a much wider area (Russell 1977a). There is thus much interest in breeding drought resistant crops as even in Britain it has been estimated that drought causes an average reduction in cereal yields of 17% (Quarrie 1980).

Different root system characteristics may be required to optimise water uptake in different environments. In areas where abundant water is available in the subsoil, breeding plants with vigorous root systems at depth may help to maximise yields (Taylor and Klepper 1978). Hurd (1968) compared the growth of seven varieties of spring wheat under water stress. He found varietal differences in drought resistance were associated with rooting pattern, the drought resistant variety Thatcher being deeper rooting than drought susceptible varieties. However in some areas the water available at depth in the soil is not recharged annually and thus a deep rooted crop could exploit it only once (Passioura 1977). Passioura (1974) suggested that for these conditions cereals should be selected which have few seminal roots and a small diameter metaxylem vessel within these roots. He reasoned that this would increase the hydraulic resistance of the root system and this would reduce the rate of water uptake and thus increase the amount of available water remaining in the soil at anthesis which should result in an increased yield. He suggested that this stratagem may improve yield in poor seasons and should not affect crop yields in good seasons since, if the topsoil were sufficiently moist, the nodal roots could develop to supply the crop with ample water.

A major strategy in the attainment of the present high yields of cereals has been the selection of genotypes which show favourable responses to increased rates of fertiliser application (Austin et al 1980). However, the increasingly high cost of fertilisers, and the realisation that the most significant contribution to world food production must come from crops grown in relatively nutrient-poor soils, has emphasised the need to improve the efficiency of crop production under limited nutrient inputs (Clarkson and Hanson 1980). The principal factors affecting the supply of nutrient to a plant are the total quantity of diffusible nutrient, the rate at which the nutrient can move and the distance it has to travel to the root (Baldwin 1975). Thus the efficiency with which a crop exploits the soil reserves of mineral nutrients may depend on root morphology (Clarkson and Hanson 1980; Wegrzyn, Hill and Baker 1980). Schenk Barber (1980) found differences in phosphorus uptake by corn genotypes grown in the field and suggested that these differences were related to the root morphologies of the genotypes. The genotype H84 x H99 generally had most roots in the topsoil where phosphorus supply was higher and they suggested that this pattern of root distribution caused the higher shoot phosphorus content of this genotype. Marykutty and Shriniwas (1978) studied the uptake by wheat varieties of $^{32}P$ from various depths in the soil. They suggested that the varieties Heera and 1577 were relatively shallow rooted as the greatest proportion of $^{32}P$ uptake occurred within a depth of 8 cm from the soil surface, the variety HDM was classified as deeper rooting as a greater proportion of $^{32}P$ uptake occurred at greater depth in the soil.

Soil compaction is often the main factor limiting crop growth after direct drilling (see Section 1). Breeding varieties adapted to compact soil conditions may thus allow increased utilisation of direct drilling. There is evidence of genetic variation in the ability of roots to grow in compact soil, although this is based on the results of relatively few experiments. Barley (1953) studied the root growth of plant species growing in irrigated perennial pastures. He found that the fairly thick roots of the grasses Phalaris tuberosa and Paspalum dilatatum could penetrate soil clods which the thin roots of perennial ryegrass (Lolium perenne) were unable to. In laboratory studies Taylor and Gardner (1960) found that the ability of roots to penetrate wax layers of increasing hardness varied with plant species. In a later study Taylor and Ratliff (1969) found differences in the root growth pressures exerted by cotton, peas and peanuts. They also noted variation in root growth pressures within species and suggested that it may be possible to select varieties capable of penetrating high strength soil layers.

# PART II

# LABORATORY EXPERIMENTS

## SECTION 6

## BARLEY VARIETY SEEDLING ROOT GROWTH

# 6. BARLEY VARIETY SEEDLING ROOT GROWTH

## 6.1 Introduction

Commercially available barley varieties have been selected over many generations for their ability to yield well when grown in conventionally cultivated soil. Studies were made to establish whether there is scope for selecting or breeding barley varieties with root systems adapted to compact soil conditions. The first step in these studies was to discover the range of variation in root system characters among varieties.

In 1976 and 1977 a survey was made of the seedling root growth of 96 barley varieties which were selected to have as diverse a geographical and/or genetic origin as possible. On completion of the first survey 9 varieties were selected from those originally surveyed. Their seedling root growth was examined in replicated experiments, and estimates of the heritability of various root characters were made.

## 6.2 Methods

### 6.2.1 First Survey

The 96 varieties studied in this survey were selected by Mr. Robin Giles from more than 1,000 varieties in the Barley Museum of the Scottish Plant Breeding Station. The varieties were selected to give a diverse geographical and genetic origin. The seed used was collected from the 1975 harvest.

As it was impossible to survey all 96 varieties simultaneously the survey was split into weekly experiments. Each week the seedling root growth of nine experimental varieties and a control variety were examined. The experimental varieties to be examined each week were chosen randomly at the start of the survey.

Each week 25 seeds of each selected variety were taken and weighed. The seeds were then surface sterilised following the method detailed in the following flow diagram.

BARLEY VARIETY SEEDLING ROOT GROWTH
SURFACE STERILISATION OF SEED

25 Dry Seeds
↓
Immersed in ethanol
for 10 seconds
↓
Washed in distilled water
↓
Immersed in 10% Deosan* v/v
for 3 minutes
↓
Washed in sterile
distilled water
↓
Last step repeated
five times

*Deosan is a commercial preparation containing sodium hypochlorite and a wetting agent.

After surface sterilisation the seeds were germinated in sterile conditions on moist filter paper in petri dishes. During the germination period and all subsequent growth the seedlings were kept in the dark in an incubator at 20$^{\circ}$C with 100% relative humidity.

After a germination period of 72 hours the number of germinated seeds were counted and 10 seedlings were selected from each variety on the basis of their uniformity (the seedlings being at the same stage of germination assessed by measuring the length of the radicle). These 10 seedlings were transferred to moist sterile filter paper supported on glass slopes mounted in frames constructed for this experiment (Plate 6.1).

Two banks of slopes totalling twenty plates were used. The 10 varieties used were replicated in each bank, with the plates in each bank as experimental units to which varieties were allocated at random. Thus each plate was allocated five seedlings of a particular variety. The seedlings were mounted at intervals along the top of each slope and were held in place by a strip of clingfilm.

The seedlings were then grown for 96 hours, at the end of this period the seminal roots produced by each seedling were counted. The diameters of all seminal roots were measured at 0.2 cm from the root tip and 0.5 cm from the seed using a Watson binocular microscope fitted with a linear graticule in a x 14 eyepiece. As these measurements took 20 to 30 minutes per plate it proved impossible to measure root lengths at the same time as this required a further 30 minutes per plate. So each plate was photographed, prints were produced from the negatives and the root lengths measured using a map measuring wheel calibrated using the ruling included in each photographic frame (Plate 6.2).

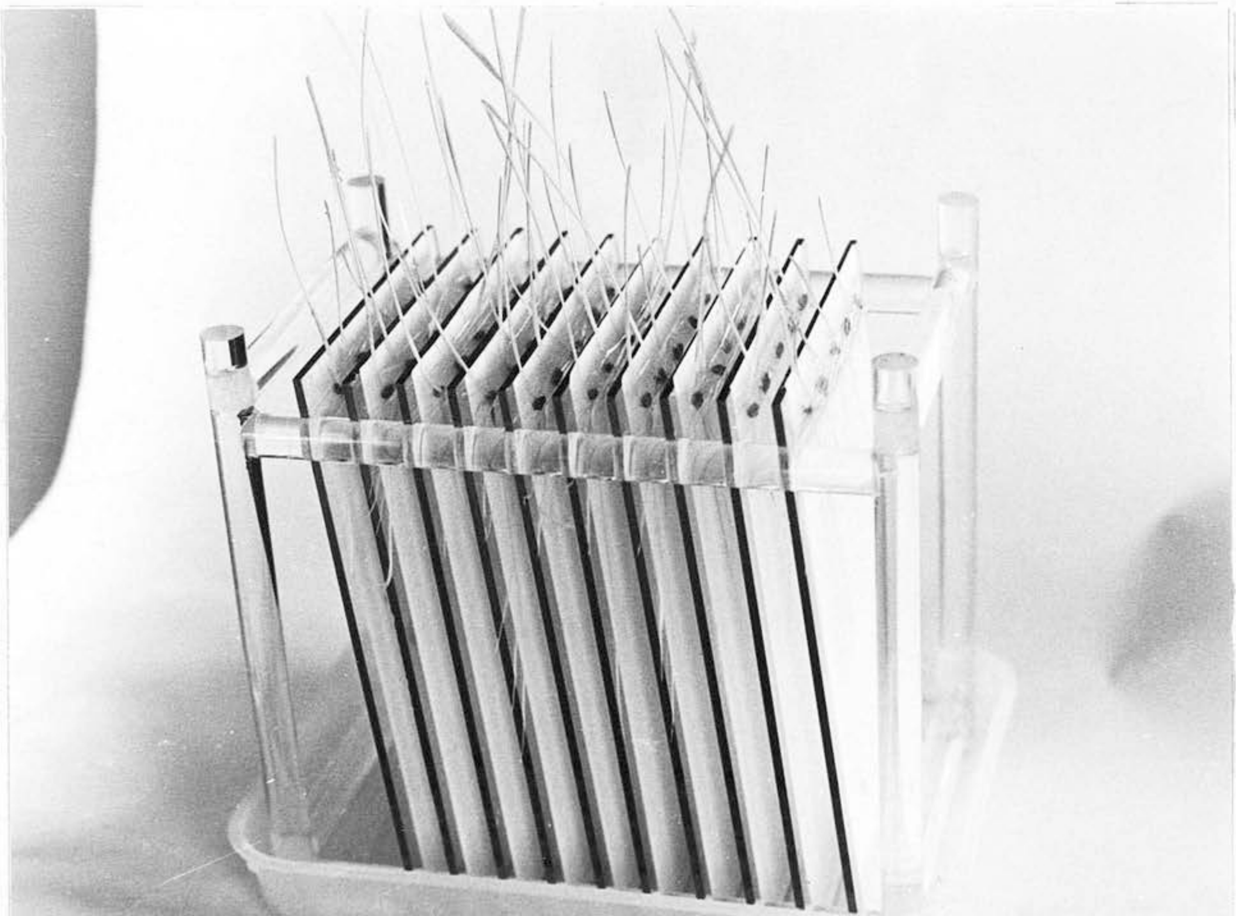

Plate 6.1 Seedling root growth apparatus


Plate 6.2 Seedlings after 4 days
growth on glass plate

### 6.2.2 Check Survey

On completion of the Major survey, 9 varieties (Table 6.1) were selected from those originally surveyed on the basis of their observed diversity in seminal root growth characteristics. The variety Georgie was included as a control and the C1 seed used was obtained from Rothwell Plant Breeders Ltd. Fresh seed stocks of the selected varieties were obtained from the Scottish Plant Breeding Stations Barley Museum, the seed having been collected from the 1976 harvest. The seedling root growth of these varieties were then examined using the same procedures as in the Major survey. The experiment was repeated three times to test the consistency of the results. The replication of the experiment allowed estimates to be made of the broad-sense heritability[ǂ] of the seedling root growth characters examined.

## 6.3 Results

### 6.3.1 First Survey

The results from this survey are presented in several tables and graphs (Tables 6.2 to 6.4 and Figures 6.1 and 6.2). The main aim of this presentation is to illustrate the mean values and ranges of expression of the various seedling characters among the varieties surveyed.

There was a considerable range of expression of seedling characters among varieties (Table 6.2). The histograms showing the frequency distribution of seedling characters illustrate the regular pattern of variation over the population of varieties (Figure 6.1). All varieties (except Ymer tetraploid, see Section 6.3.2) seem to belong to a single population group within which there is a 'normal' variation in phenotypic characteristics. The summary of results given in Table 6.3 gives little evidence of significant differences in seedling root characters between groups of varieties of different ear type and ancestry.

There is some evidence of a correlation between certain seedling root characters (Table 6.4). There are strong positive relationships of mean length and mean numbers of seminal roots with the total length of the seedling root system;

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[ǂ] Broad sense heritability was calculated by taking the ratio of genotypic variance to phenotypic variance.

these are further illustrated in Figure 6.2.

Percentage germination was also positively correlated with both seedling and mean seminal root length, although from Figure 6.1(a) it can be seen that this correlation is not as strong as the level of significance may indicate. Mean root diameter was negatively correlated with both seedling and mean seminal root length, however this result may have been unduly large due to the inclusion in the analysis of the variety Ymer tetraploid which had short, relatively thick roots (see Section 6.3.2 and Table 6.2).

It had been intended to perform a statistical analysis of the significance of differences in seedling characters among the varieties surveyed. This analysis was dependent on the use of a control variety which could be used as a reference to enable comparisons to be made between varieties grown in different weeks. As the survey progressed it became apparent that the seed of the control variety (Sundance) germinated poorly and gave unusually variable results both between plants and between weeks, as judged against the response of other varieties in this trial and in the check survey. This could have been caused by variations in environmental conditions during the survey which may have occurred despite the rigid procedures adopted to ensure uniformity of seed preparation operations and seedling incubation conditions during the survey. However the variable results could also have been due to between seed differences in internal environment affecting the expression of seedling characters (see Section 6.4). To allow Sundance to be used as the control variety a larger quantity of its seed was required which had to be obtained from a different source to that of the other varieties used in the survey. Sundance seed was gathered from field experiments at the East of Scotland College of Agriculture and it is possible that the seed batch may have thus been comprised of seed with a large range in weights or chemical constituents.

Because of the variability in the results from the control variety it was thought unwise to perform statistical tests comparing the performance of individual varieties examined in the first survey. However, the results of the check survey given below give strong evidence that a large part of the variation in expression of certain seedling characters is under genetic control.

6.3.2 Check Survey

The varieties used in the check survey were selected on the basis of their diversity of seminal root characters as exhibited in the first survey. There were significant differences in seminal root characters among the varieties in the check survey (Table 6.5). A comparison of results for the varieties included in both surveys showed that their expression of seminal root number and seedling root length in the two years was significantly correlated (Table 6.6).

The calculation of broad-sense heritabilities of seminal root characters among the population of varieties selected for the check survey revealed the proportion of variation attributable to genotypic effects (Table 6.7). Seminal root number was the most highly heritable character followed in order of decreasing magnitude by mean seedling root length, mean seminal root length and root diameter. For root diameter more weight is placed on the analysis excluding Ymer tetraploid as its mean root diameter is nearly 50% greater than that of the other varieties (Table 6.5).

The seed used in the check survey was found to be markedly lighter than that used in the first survey (Table 6.7). The smaller seed produced in 1976 may have been caused by the drought in the summer of that year (see Section 4.1). With the exception of root diameter the values of all seedling characters were reduced to some degree in the check survey as compared with the first survey (Table 6.8).

TABLE 6.1 SEEDLING ROOT GROWTH OF BARLEY VARIETIES

Varieties used in the check survey

| | |
|---|---|
| Ymer tetraploid: | Ymer (diploid) is a Swedish bred (Svalov Plant Breeding Station) 2-row barley. This tetraploid form is derived from a Canadian source and is probably a colchicine induced autotetraploid. |
| Afghan R 1395 (Ghorbana): | 6 row cultivated barley collected by Reading University expedition in 1965 from a stack in Ghorban village (6,700 ft.) Afghanistan. |
| Akashinriki: | 6 row barley, naked seeded Japanese dwarf form. |
| Sumiremochi: | 6 row barley, naked seeded Japanese with waxy endosperm due to high amylopectin/amylose ratio in endosperm. |
| Valticky: | 2 row barley bred in Czechoslovakia. |
| Charlottetown 80: | 2 row barley derived from English land race material selected in Canada. |
| Varunda: | 2 row barley recently bred at Wageningen Plant Breeding Station, Holland. |
| Ringve: | 6 row barley recently bred at Møystad, Norway. |
| Nepal NB 68 A: | 6 row barley, naked, collected from Ghat village (8150 ft.) by University College of North Wales expedition in 1971. |
| Georgie: | 2 row barley recently bred by Rothwell Plant Breeders, Grimsby. |

TABLE 6.2(a) <u>SEEDLING ROOT GROWTH OF BARLEY VARIETIES: FIRST SURVEY</u>

MEANS OF SIX SEEDLING CHARACTERS IN THE 96 VARIETIES SURVEYED

| VARIETY | TYPE+ | 2 or 6 ROW | V(1)+ | V(2)+ | V(3)+ | V(4)+ | V(5)+ | V(6)+ |
|---|---|---|---|---|---|---|---|---|
| H.SPONTANEUM | A | 2 | 3.6 | 23.5 | 6.5 | 0.44 | 5.3 | 4 |
| AFGHAN R113(GARMO) | L | 2 | 8.4 | 73.5 | 8.7 | 0.50 | 6.1 | 100 |
| DRUSP | L | 2 | 8.7 | 62.5 | 7.2 | 0.47 | 6.3 | 67 |
| ESPERANCE | L | 2 | 8.0 | 71.6 | 8.9 | 0.44 | 8.1 | 92 |
| ETHIOPIAN (ST 473) | L | 2 | * | * | * | * | 8.3 | 12 |
| HEN GYMRO HAIDO HEN FFASIWN | L | 2 | 8.1 | 67.8 | 8.4 | 0.53 | 7.0 | 45 |
| LA PREVISION 19 | L | 2 | 7.9 | 65.9 | 8.3 | 0.49 | 6.2 | 75 |
| LOOSDORFER | L | 2 | 7.0 | 52.7 | 7.5 | 0.47 | 5.3 | 100 |
| OLD CORNISH | L | 2 | 7.1 | 50.3 | 7.1 | 0.45 | 5.1 | 100 |
| OLD IRISH | L | 2 | 7.0 | 63.6 | 9.1 | 0.49 | 5.8 | 100 |
| RUSSIAN (KUBAN) | L | 2 | 5.4 | 31.2 | 5.7 | 0.50 | 5.3 | 22 |
| SCOTCH COMMON B7 (4) | L | 2 | 6.7 | 61.4 | 9.2 | 0.44 | 6.2 | 94 |
| TURKISH 527(KASTAMONU) | L | 2 | 5.6 | 47.4 | 8.5 | 0.48 | 7.2 | 82 |
| TURKISH 1106(TOKAT) | L | 2 | 6.0 | 52.8 | 8.8 | 0.50 | 6.8 | 76 |
| WEIHENSTEPHAN CP127422 | M | 2 | 7.5 | 68.5 | 9.1 | 0.48 | 4.9 | 100 |
| YMER TETRAPLOID | M | 2 | 6.9 | 20.2 | 2.9 | 0.67 | 6.5 | 80 |
| AKKA | V | 2 | 6.4 | 36.7 | 5.7 | 0.46 | 6.6 | 13 |
| AMSEL | V | 2 | 7.0 | 55.0 | 7.9 | 0.44 | 11.0 | 95 |
| ARCHER | V | 2 | 8.0 | 48.8 | 6.1 | 0.48 | 6.3 | 17 |
| BOREHAM WARRIOR | V | 2 | 6.5 | 47.9 | 7.4 | 0.45 | 6.4 | 100 |
| CHARLOTTETOWN 80 | V | 2 | 8.1 | 70.0 | 8.6 | 0.43 | 5.3 | 100 |
| DAMPIER | V | 2 | 8.4 | 40.3 | 4.8 | 0.50 | 6.8 | 100 |
| DEBA ABED | V | 2 | 7.4 | 63.9 | 8.6 | 0.47 | 5.3 | 100 |
| EMIR | V | 2 | 7.7 | 56.2 | 7.3 | 0.47 | 5.2 | 72 |
| GERKRA | V | 2 | 7.2 | 69.9 | 9.7 | 0.48 | 5.5 | 95 |
| GOLDEN MELON (TOCHIQI) | V | 2 | 8.8 | 63.1 | 7.2 | 0.45 | 5.6 | 71 |
| GOLDEN PROMISE | V | 2 | 6.9 | 51.6 | 7.5 | 0.45 | 6.1 | 74 |

+See Key Table 6.2(d)

*Missing Values

TABLE 6.2(b) SEEDLING ROOT GROWTH OF BARLEY VARIETIES: FIRST SURVEY

MEANS OF SIX SEEDLING CHARACTERS IN THE 96 VARIETIES SURVEYED

| VARIETY | TYPE+ | 2 or 6 ROW | V(1)+ | V(2)+ | V(3)+ | V(4)+ | V(5)+ | V(6)+ |
|---|---|---|---|---|---|---|---|---|
| GUNILLA | V | 2 | 7.6 | 62.6 | 8.2 | 0.52 | 6.2 | 88 |
| HADO STRENG | V | 2 | 7.5 | 52.1 | 6.9 | 0.48 | 5.1 | 86 |
| HANNA | V | 2 | 7.5 | 69.0 | 9.2 | 0.45 | 5.5 | 71 |
| JET | V | 2 | 7.0 | 48.0 | 6.9 | 0.47 | 6.1 | 67 |
| KENIA | V | 2 | 7.3 | 62.6 | 8.6 | 0.47 | 4.8 | 83 |
| KLINTSO | V | 2 | 7.2 | 76.7 | 10.6 | 0.45 | * | * |
| KLAGES | V | 2 | 7.3 | 50.7 | 6.9 | 0.45 | 9.0 | 73 |
| LARA | V | 2 | 7.4 | 70.1 | 9.5 | 0.43 | 10.6 | 71 |
| LAMI | V | 2 | 7.5 | 52.8 | 7.0 | 0.44 | 10.3 | 96 |
| MAYTHORPE | V | 2 | 7.5 | 79.9 | 10.7 | 0.44 | * | * |
| MARIS MINK | V | 2 | 7.6 | 49.4 | 6.5 | 0.46 | 5.1 | 100 |
| MAZURKA | V | 2 | 6.7 | 57.1 | 8.5 | 0.45 | 5.2 | 100 |
| MIRRA | V | 2 | 5.7 | 55.7 | 9.8 | 0.47 | * | * |
| MIDAS | V | 2 | 7.6 | 47.8 | 6.3 | 0.46 | 4.9 | 100 |
| MONA | V | 2 | 7.0 | 49.6 | 7.1 | 0.47 | 5.6 | 100 |
| NACKTA | V | 2 | 6.1 | 60.9 | 10.0 | 0.47 | 4.7 | 67 |
| OLLI | V | 2 | 7.5 | 54.2 | 7.2 | 0.43 | 8.0 | 76 |
| PRIMUS | V | 2 | 7.4 | 82.4 | 11.1 | 0.43 | 9.8 | 91 |
| PROCTOR | V | 2 | 6.9 | 65.2 | 9.4 | 0.46 | 4.7 | 100 |
| RESEARCH | V | 2 | 7.9 | 61.6 | 7.8 | 0.47 | 5.4 | 80 |
| SPARTAN | V | 2 | 6.8 | 42.6 | 6.3 | 0.44 | 12.8 | 86 |
| SUNDANCE | V | 2 | 6.1 | 58.0 | 9.5 | 0.45 | 4.9 | 100 |
| TRUMPF | V | 2 | 7.8 | 74.9 | 9.6 | 0.47 | 6.4 | 100 |
| UNION | V | 2 | 6.9 | 49.4 | 7.2 | 0.47 | 5.1 | 83 |
| VARUNDA | V | 2 | 8.6 | 61.1 | 7.1 | 0.46 | 6.0 | 96 |
| VALTICKY | V | 2 | 6.4 | 60.8 | 9.5 | 0.49 | 5.4 | 95 |
| WING | V | 2 | 6.6 | 61.9 | 9.4 | 0.47 | 8.0 | 78 |
| WPQ M 7118-702-10 | V | 2 | 6.8 | 41.7 | 6.1 | 0.50 | 8.2 | 17 |
| ZEPHYR | V | 2 | 7.7 | 56.7 | 7.4 | 0.47 | 5.6 | 91 |
| SULU | X | 2 | 5.9 | 40.7 | 6.9 | 0.48 | 5.9 | 68 |

+See Key Table 6.2(d)

*Missing Values

TABLE 6.2(c) SEEDLING ROOT GROWTH OF BARLEY VARIETIES: FIRST SURVEY

MEANS OF SIX SEEDLING CHARACTERS IN THE 96 VARIETIES SURVEYED

| VARIETY | TYPE+ | 2 or 6 ROW | V(1)+ | V(2)+ | V(3)+ | V(4)+ | V(5)+ | V(6)+ |
|---|---|---|---|---|---|---|---|---|
| H.AGRIOCRITHON | A | 6 | 7.1 | 63.8 | 9.0 | 0.43 | * | * |
| AFGHAN R1395(GHORBAND) | L | 6 | 6.5 | 65.6 | 10.1 | 0.46 | 8.8 | 100 |
| ALGERIAN | L | 6 | 6.1 | 23.0 | 3.7 | 0.51 | 6.4 | 6 |
| CEBADA NEGRA | L | 6 | 7.0 | 44.9 | 6.4 | 0.49 | 7.9 | 57 |
| EGYPTIAN | L | 6 | 6.0 | 54.6 | 9.1 | 0.48 | * | * |
| INDIAN (NP13) | L | 6 | 6.3 | 55.3 | 8.8 | 0.40 | 5.3 | 48 |
| MOROCCO | L | 6 | 6.1 | 44.5 | 7.3 | 0.53 | 8.9 | 24 |
| NEPAL CB 9A (BAGA) | L | 6 | 5.7 | 35.3 | 6.2 | 0.43 | 5.4 | 96 |
| NEPAL NB 68A(GHAT) | L | 6 | 5.2 | 35.3 | 6.8 | 0.43 | 6.5 | 100 |
| PERSIAN (ADANA) | L | 6 | 6.0 | 53.1 | 8.8 | 0.48 | 11.0 | 5 |
| PERUVIAN | L | 6 | 7.2 | 49.9 | 6.9 | 0.47 | 6.9 | 85 |
| SCOTCH BERE | L | 6 | 5.8 | 58.0 | 10.0 | 0.50 | 8.6 | 100 |
| TIBETAN(H247) | L | 6 | 7.0 | 60.3 | 8.6 | 0.47 | 9.2 | 100 |
| YUGOSLAVIAN 4082 | L | 6 | 6.4 | 58.6 | 9.2 | 0.46 | 14.1 | 78 |
| BRACHYTIC 119 | M | 6 | 6.7 | 54.5 | 8.1 | 0.44 | 4.4 | 89 |
| UZU | M | 6 | 5.0 | 35.2 | 7.0 | 0.51 | 7.8 | 89 |
| VARIEGATED ALBERTA | M | 6 | 6.7 | 57.4 | 8.6 | 0.43 | 9.8 | 95 |
| AKASHINRIKI | V | 6 | 5.0 | 43.5 | 8.7 | 0.53 | 6.8 | 100 |
| ASSE | V | 6 | 6.2 | 43.7 | 7.1 | 0.50 | 8.7 | 92 |
| ASPLUND | V | 6 | 7.6 | 64.9 | 8.5 | 0.43 | * | * |
| ATLAS 68 | V | 6 | 6.2 | 43.5 | 7.0 | 0.48 | 9.8 | 83 |
| BIGO | V | 6 | 6.2 | 60.2 | 9.7 | 0.49 | 13.9 | 95 |
| CLERMONT | V | 6 | 5.9 | 43.3 | 7.3 | 0.52 | 12.3 | 95 |
| DEA | V | 6 | 6.3 | 38.7 | 6.1 | 0.47 | 4.8 | 83 |
| GLACIER | V | 6 | 6.9 | 56.6 | 8.2 | 0.50 | 11.0 | 64 |

+See Key Table 6.2(d) *Missing Values

TABLE 6.2(d) SEEDLING ROOT GROWTH OF BARLEY VARIETIES: FIRST SURVEY

MEANS OF SIX SEEDLING CHARACTERS IN THE 96 VARIETIES SURVEYED

| VARIETY | TYPE+ | 2 or 6 ROW | V(1)+ | V(2)+ | V(3)+ | V(4)+ | V(5)+ | V(6)+ |
|---|---|---|---|---|---|---|---|---|
| IREDALL | V | 6 | 6.9 | 60.0 | 8.7 | 0.42 | 8.6 | 42 |
| LION 66 | V | 6 | 5.8 | 42.1 | 7.3 | 0.44 | 9.0 | 23 |
| MANCHURIA | V | 6 | 6.9 | 59.5 | 8.6 | 0.42 | 7.1 | 100 |
| MARRET HOODED | V | 6 | 7.7 | 34.8 | 4.5 | 0.47 | 10.2 | 100 |
| O.A.C. 21 | V | 6 | 7.0 | 64.0 | 9.1 | 0.44 | 11.0 | 82 |
| PEATLAND | V | 6 | 7.5 | 57.2 | 7.6 | 0.41 | 6.5 | 100 |
| PREFECT | V | 6 | 6.2 | 54.5 | 8.8 | 0.41 | 7.6 | 68 |
| REKA | V | 6 | 6.2 | 45.3 | 7.3 | 0.48 | 5.6 | 5 |
| RINGVE | V | 6 | 6.6 | 46.3 | 7.0 | 0.43 | 8.0 | 32 |
| SMOOTH AWN 88 | V | 6 | 6.1 | 50.1 | 8.2 | 0.44 | 4.9 | 100 |
| SUMIREMOCHI(SAGHALEIN) | V | 6 | 5.4 | 45.0 | 8.3 | 0.46 | 7.3 | 92 |
| BAJO ARGON | X | 6 | 5.4 | 50.9 | 9.4 | 0.52 | 13.7 | 60 |
| HOKUDO | X | 6 | 5.9 | 48.6 | 8.3 | 0.45 | 7.9 | 47 |
| MASSAUX ABUNDANCIA | X | 6 | 5.8 | 46.4 | 8.0 | 0.49 | 5.7 | 79 |

+KEY

TYPE: A = Ancestral Type, L = Land Variety, M = Unusual Variant,
V = Modern Variety, X = Unknown Origin.

V(1) = Mean number of seminal roots per seedling

V(2) = Mean length seedling root system (cm)

V(3) = Mean length seminal root axes (cm)

V(4) = Mean root diameter (mm)

V(5) = Mean seed weight (g x $10^{-2}$)

V(6) = Germination percentage

TABLE 6.3 SEEDLING ROOT GROWTH OF BARLEY VARIETIES: FIRST SURVEY

Summary of seedling characters in groups of variety types
Mean and range ( )

| Variety Type / Character | All Varieties | 2-row barleys: Modern Variety | 2-row barleys: Land Variety | 2-row barleys: Ancestral Type | 2-row barleys: Unusual Variant | 2-row barleys: Unknown Origin | 6-row barleys: Modern Variety | 6-row barleys: Land Variety | 6-row barleys: Ancestral Type | 6-row barleys: Unusual Variant | 6-row barleys: Unknown Origin |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean number of seminal roots per seedling | 6.8 (3.6-8.8) | 7.3 (5.7-8.8) | 7.2 (5.4-8.7) | 3.6 - | 7.2 (1.5-6.9) | 5.9 - | 6.5 (5.0-7.7) | 6.3 (5.2-7.2) | 7.1 - | 6.1 (5.0-6.7) | 5.7 (5.4-5.9) |
| Mean length (cm) seedling root system | 53.9 (20.2-82.4) | 56.7 (36.7-82.4) | 58.4 (31.2-73.5) | 23.5 - | 44.4 (20.2-68.5) | 40.7 - | 50.2 (34.8-64.9) | 47.6 (23.0-65.6) | 63.8 - | 49.0 (35.2-57.4) | 48.6 (46.4-50.9) |
| Mean length (cm) seminal root axes | 7.9 (2.9-11.1) | 7.9 (4.8-11.1) | 8.1 (5.7-9.2) | 6.5 - | 6.0 (2.9-9.1) | 6.9 - | 7.8 (4.5-9.7) | 7.8 (3.7-10.1) | 9.0 - | 7.9 (7.0-8.6) | 8.6 (8.0-9.4) |
| Mean root diameter (mm) | 0.47 (0.40-0.67) | 0.46 (0.43-0.52) | 0.48 (0.44-0.53) | 0.44 - | 0.58 (0.48-0.67) | 0.48 - | 0.46 (0.41-0.53) | 0.47 (0.40-0.53) | 0.43 | 0.46 (0.43-0.51) | 0.49 (0.45-0.52) |
| Mean seed weight (g x $10^{-2}$) | 7.2 (4.4-14.1) | 6.6 (4.7-12.8) | 6.4 (5.1-8.3) | 5.3 - | 5.7 (4.9-6.5) | 5.9 | 8.5 (4.8-13.9) | 8.3 (5.3-14.1) | * | 7.3 (4.4-9.8) | 9.1 (5.7-13.7) |
| Percentage germination | 76 (4-100) | 82 (13-100) | 74 (12-100) | 4 | 90 (80-100) | 68 | 75 (5-100) | 67 (5-100) | * | 91 (89-95) | 62 (47-79) |
| Number of varieties per group | 96 | 40 | 13 | 1 | 2 | 1 | 19 | 13 | 1 | 3 | 3 |

TABLE 6.4 SEEDLING ROOT GROWTH OF BARLEY VARIETIES: FIRST SURVEY

Correlation of 6 seedling characters
among the 96 varieties

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mean length (cm), seedling root system | X(1) | 1.000 | | | | | |
| Mean length (cm), seminal root axes | X(2) | 0.805 | 1.000 | | | | |
| Mean root diameter (mm) | X(3) | - 0.304 | - 0.306 | 1.000 | | | |
| Mean seed weight ($g \times 10^{-2}$) | X(4) | 0.005 | 0.139 | 0.037 | 1.000 | | |
| Percentage germination | X(5) | 0.375 | 0.285 | - 0.094 | - 0.077 | 1.000 | |
| Mean number of seminal root axes | X(6) | 0.562 | - 0.028 | - 0.0712 | - 0.154 | 0.271 | 1.000 |
| | | X(1) | X(2) | X(3) | X(4) | X(5) | X(6) |

Degrees of Freedom = 87

Correlation coefficients underlined _____
are significant at $P < .001$

Correlation coefficients underlined - - -
are significant at $P < 0.01$

FIGURE 6.1 SEEDLING ROOT GROWTH OF BARLEY VARIETIES: FIRST SURVEY

HISTOGRAMS SHOWING THE DISTRIBUTION OF SEEDLING CHARACTERISTICS AMONG THE 96 VARIETIES SURVEYED

FIGURE 6.1(a) Mean Seed Weight ($g \times 10^{-2}$)

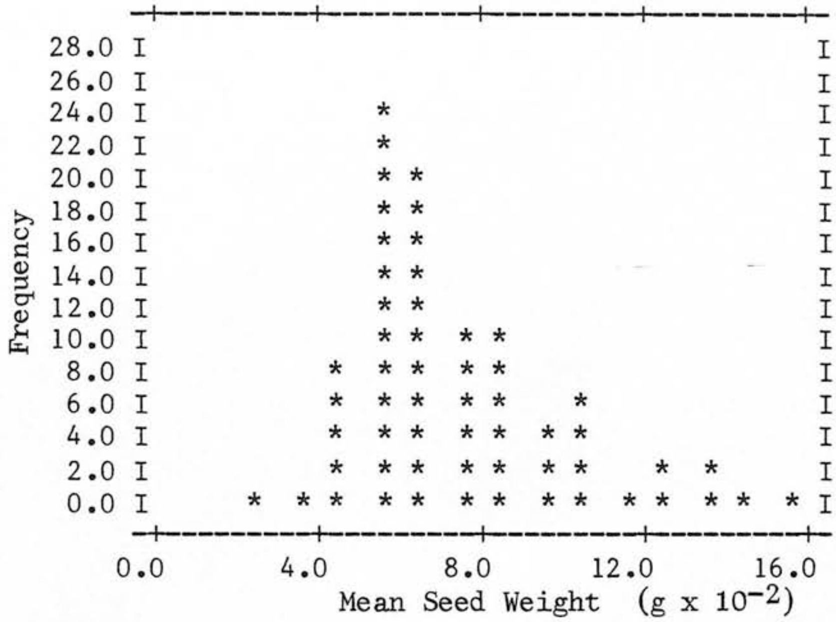



FIGURE 6.1(b) Germination Percentage

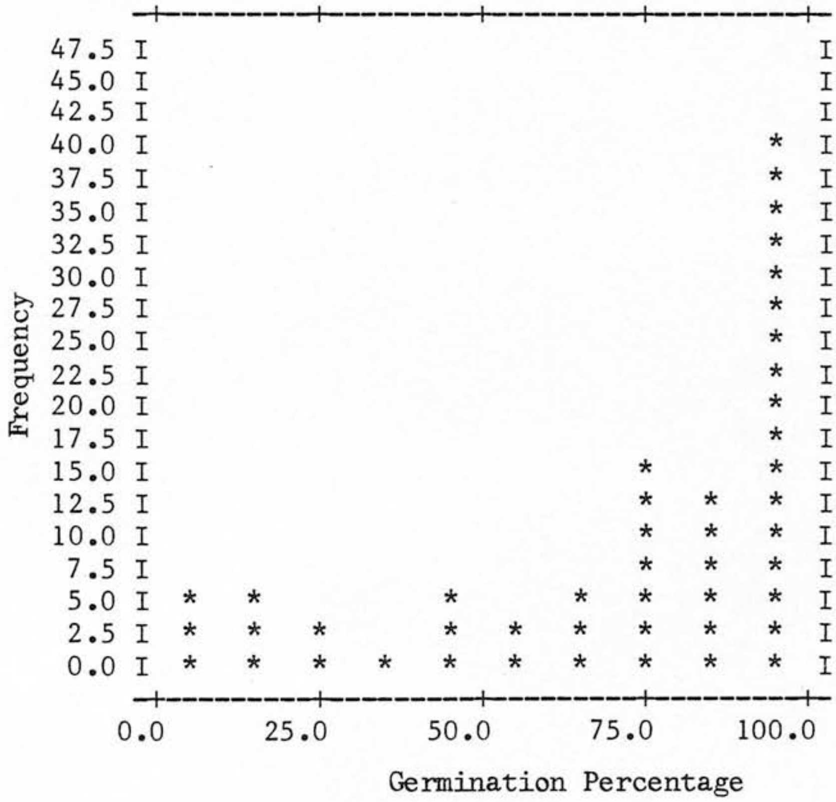


FIGURE 6.1 SEEDLING ROOT GROWTH OF BARLEY VARIETIES: FIRST SURVEY

HISTOGRAMS SHOWING THE DISTRIBUTION OF SEEDLING CHARACTERISTICS AMONG THE 96 VARIETIES SURVEYED

FIGURE 6.1(c) Mean Number of Seminal Roots per Seedling

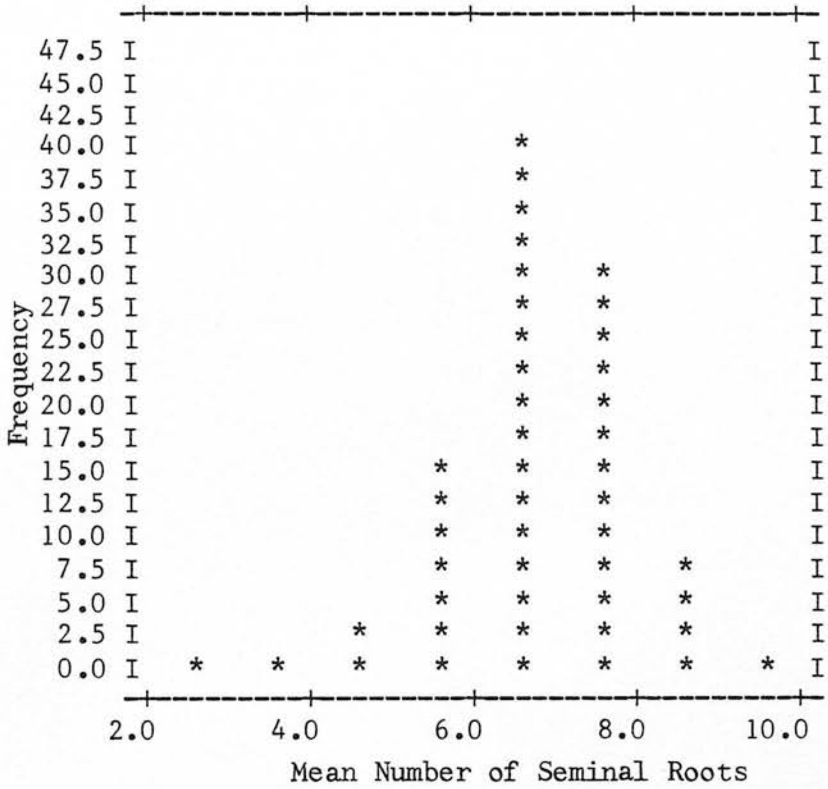



FIGURE 6.1(d) Mean Root Diameter (mm)

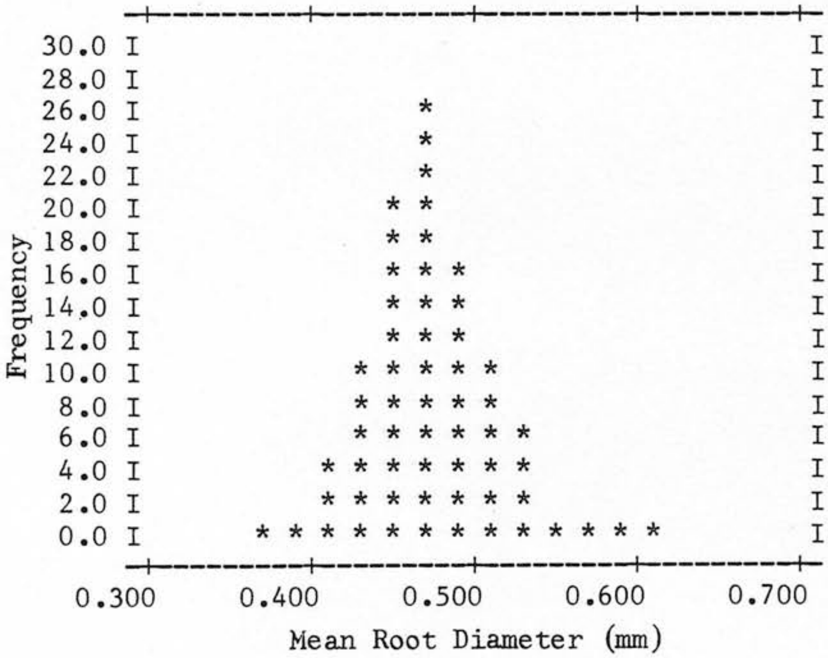


FIGURE 6.1 SEEDLING ROOT GROWTH OF BARLEY VARIETIES: FIRST SURVEY

HISTOGRAMS SHOWING THE DISTRIBUTION OF SEEDLING CHARACTERISTICS AMONG THE 96 VARIETIES SURVEYED

FIGURE 6.1(e) Mean Length Seedling Root System (cm)

```
     -+---------+---------+---------+---------+-
30.0 I                                         I
28.0 I                      *                  I
26.0 I                      *                  I
24.0 I                  *   *   *              I
22.0 I                  *   *   *              I
20.0 I                  *   *   *              I
18.0 I                  *   *   *              I
16.0 I                  *   *   *              I
14.0 I                  *   *   *              I
12.0 I                  *   *   *              I
10.0 I                  *   *   *              I
 8.0 I                  *   *   *              I
 6.0 I              *   *   *   *   *          I
 4.0 I              *   *   *   *   *          I
 2.0 I          *   *   *   *   *   *          I
 0.0 I  *   *   *   *   *   *   *   *   *   *  I
     -+---------+---------+---------+---------+-
     0.0      25.0      50.0      75.0     100.0
```

Frequency

Seedling Root System Length (cm)

FIGURE 6.1(f) Mean Length Seminal Root Axes (cm)

```
     -+---------+---------+---------+---------+-
30.0 I                                         I
28.0 I                                         I
26.0 I                        *                I
24.0 I                        *                I
22.0 I                        *                I
20.0 I                    *   *                I
18.0 I                *   *   *   *            I
16.0 I                *   *   *   *            I
14.0 I                *   *   *   *            I
12.0 I                *   *   *   *            I
10.0 I                *   *   *   *            I
 8.0 I                *   *   *   *            I
 6.0 I                *   *   *   *            I
 4.0 I                *   *   *   *            I
 2.0 I        *   *   *   *   *   *   *        I
 0.0 I*   *   *   *   *   *   *   *   *   *   *I
     -+---------+---------+---------+---------+-
     2.5       5.0       7.5      10.0      12.5
```

Frequency

Seminal Root Length (cm)

FIGURE 6.2 SEEDLING ROOT GROWTH OF BARLEY VARIETIES: FIRST SURVEY

SCATTER DIAGRAMS SHOWING THE RELATIONSHIP BETWEEN SELECTED SEEDLING CHARACTERISTICS IN THE 96 VARIETIES SURVEYED

FIGURE 6.2(a) Seedling Root Length Versus Germination Percentage

```
                    -+---------+---------+---------+---------+-
               90.0 I                                         I
               85.0 I                                         I
               80.0 I                                    *    I
               75.0 I                                        2I
Mean Length    70.0 I                  *         2        ** 2I
Seedling       65.0 I                            * *  2 *    4I
Root System    60.0 I                 *         2   2*     4 4I
(cm)           55.0 I  *                *      ** *2     2 3 3I
               50.0 I       *           *    *  * **  *2     6I
               45.0 I  *       *  *         *        *2*  2* *I
               40.0 I       * *                 *     *      *I
               35.0 I     *                              * * 2I
               30.0 I         *                               I
               25.0 I  2                                      I
               20.0 I                                *        I
                    -+---------+---------+---------+---------+-
                    0.0      25.0      50.0      75.0     100.0
                              Germination Percentage
```

Asterisks denote results for one variety and are replaced by numbers when several points coincide.

FIGURE 6.2 <u>SEEDLING ROOT GROWTH OF BARLEY VARIETIES: FIRST SURVEY</u>

SCATTER DIAGRAMS SHOWING THE RELATIONSHIP BETWEEN SELECTED SEEDLING CHARACTERISTICS IN THE 96 VARIETIES SURVEYED

FIGURE 6.2(b) <u>Seminal Root Number Versus Seedling Root Length</u>

Mean Number of Seminal Roots per Seedling

```
    -+---------+---------+---------+---------+-
9.20 I                                       I
8.80 I                        2              I
8.40 I               *       *    *          I
8.00 I                   *    ******         I
7.60 I             *    **222 *2*2   **      I
7.20 I                 **4** *22 *  *        I
6.80 I       *        2 ****322*             I
6.40 I              2 2**  2*2 *             I
6.00 I        *      *****2***               I
5.60 I             *  * 2  **                I
5.20 I           * 2  ** *                   I
4.80 I                                       I
4.40 I                                       I
4.00 I                                       I
3.60 I        *                              I
3.20 I                                       I
    -+---------+---------+---------+---------+-
    0.0      25.0      50.0      75.0     100.0
      Mean Length Seedling Root System (cm)
```

FIGURE 6.2(c) <u>Seedling Versus Seminal Root Length</u>

Mean Length Seedling Root System (cm)

```
    -+---------+---------+---------+---------+-
90.0 I                                       I
85.0 I                                       I
80.0 I                                **     I
75.0 I                        *  *   *       I
70.0 I                       2 2***          I
65.0 I                  *   23 3 * *         I
60.0 I                 ** *  2* 23*2         I
55.0 I                 *23 2*24*  *          I
50.0 I             *** 6*2  2    *           I
45.0 I              ** 33  ****              I
40.0 I        *    2   **                    I
35.0 I       *    * * **                     I
30.0 I            *                          I
25.0 I     *         *                       I
20.0 I  *                                    I
    -+---------+---------+---------+---------+-
    2.5       5.0       7.5      10.0      12.5
        Mean Length Seminal Root Axes (cm)
```

TABLE 6.5 SEEDLING ROOT GROWTH OF BARLEY VARIETIES CHECK SURVEY

Seminal root characteristics of 10 barley varieties

| Variety | Seedling Character | | | |
|---|---|---|---|---|
| | Mean Seminal Root Number | Mean Seminal Root Length (cm) | Mean Total Root Length (cm) | Mean Root Diameter (mm) |
| Georgie | 5.9 | 5.7 | 34.0 | 0.48 |
| Ymer tetraploid | 5.7 | 2.1 | 14.3 | 0.69 |
| Afghan R1395 | 6.1 | 6.7 | 41.8 | 0.47 |
| Akashinriki | 4.1 | 6.3 | 26.0 | 0.49 |
| Sumiremochi | 5.1 | 5.2 | 27.4 | 0.46 |
| Nepal NB 68A | 4.3 | 5.5 | 27.2 | 0.45 |
| Valticky | 6.3 | 7.3 | 46.5 | 0.48 |
| Charlottetown 80 | 7.6 | 6.8 | 51.4 | 0.49 |
| Varunda | 7.6 | 6.3 | 48.1 | 0.49 |
| Ringve | 6.9 | 6.0 | 41.4 | 0.45 |
| Statistical significance | *** | *** | *** | *** |
| SED | 0.41 | 0.63 | 4.47 | 0.013 |

TABLE 6.6 SEEDLING ROOT GROWTH OF BARLEY VARIETIES

Correlation of seedling characters of varieties between the first survey and check survey

| Seedling character | Analysed including Ymer tetraploid | | Analysed excluding Ymer tetraploid | |
|---|---|---|---|---|
| | Correlation coefficient | Statistical significance | Correlation coefficient | Statistical significance |
| Mean seminal root number | 0.93 | *** | 0.95 | *** |
| Mean seminal root diameter | 0.93 | *** | 0.53 | ns |
| Mean length seedling root system | 0.93 | *** | 0.88 | ** |
| Mean length seminal root axes | 0.91 | *** | 0.62 | ns |
| Mean seed weight | - 0.12 | ns | - 0.10 | ns |

TABLE 6.7 SEEDLING ROOT GROWTH OF BARLEY VARIETIES CHECK SURVEY

Broad sense heritability

| Root Character | Heritability |
|---|---|
| Mean seminal root number | 74% |
| Mean seminal root length | 61% |
| Mean total root length | 69% |
| Mean root diameter | *90% (46%) |

*The value in brackets is the broad sense heritability from an analysis excluding Ymer tetraploid

TABLE 6.8 SEEDLING ROOT GROWTH OF BARLEY VARIETIES

Results summary over the nine varieties included in the first and check surveys

| SEEDLING CHARACTER | FIRST SURVEY MEAN | FIRST SURVEY (RANGE) | CHECK SURVEY MEAN | CHECK SURVEY (RANGE) |
|---|---|---|---|---|
| Mean seminal root number | 6.5 | (3.6) | 6.0 | (3.5) |
| Mean seminal root diameter (mm) | 0.48 | (0.24) | 0.49 | (0.24) |
| Mean length, seedling root system (cm) | 49.8 | (50.8) | 36.0 | (37.1) |
| Mean length, seminal root axes (cm) | 7.7 | (7.2) | 5.8 | (5.2) |
| Mean seed weight (g x $10^{-6}$) | 6.7 | (3.4) | 4.5 | (4.0) |
| Germination percentage | 90 | (78) | 70 | (45) |

## 6.4 Discussion

The varieties examined in the surveys were selected to have as diverse a geographical and/or genetic origin as possible. It is hoped that the pattern of variation among the surveyed varieties would reflect that among the many hundreds of barley varieties in existence.

The summary of results from the first survey gave little evidence of major differences between the groups into which the barley varieties were classified (Table 6.3). Furthermore the histograms showing the variation in seedling characters over the population show no evidence of any discontinuous variation in any characters (Figure 6.1). The intervarietal variation in seedling root characters had a distribution typical of quantitative genetic characters (Strickberger 1968). It is thought that the expression of quantitative characters are controlled by polygenes; polygenes being defined as genes with a small effect on a particular character which can supplement each other to produce observable quantitative changes (Strickberger 1968). These quantitative effects may be additive, i.e. they can be added together to produce phenotypes which are the sum total of the negative and positive effects of individual genes. A normal distribution of phenotypes is indicative of polygenes with additive effects; non-additivity and interactions of various kinds cause the distribution of phenotypes to be skewed.

In general the frequency histograms of seedling root characters show a normal distribution of phenotypes (Figure 6.3), indicating that the characters are controlled by additive polygenic systems. After a survey of the root system characters of five barley varieties and their $F_1$ and $F_2$ hydrids, Surma et al (1978) also concluded that root system characters in barley were controlled by additive polygenic systems. Monyo and Whittington (1970) in a genetic analysis of root growth in wheat, also found that variations in root characters were determined by polygenic systems which were largely additive. However they also found, after following plants to maturity, that root characters were markedly influenced by single genes determining the length of the vegetative period. In the present survey the histogram of seminal root length does show a slight positive skewness indicating that the expression of this character may be influenced by non-additive or interacting polygenes, although the skewness may merely be a reflection of an environmental effect distorting the expression of the genotype (Figure 6.1(e)).

The distribution of phenotypes within a population does not necessarily correspond with the underlying distribution of genotypes. The closeness of the correlation between phenotype and genotype depends on the relative action of genotype and environment; thus the greater the environmental effect on a character the less reliable is the relationship between phenotypic and genotypic distribution. In the check survey the experimental design allowed the total phenotypic variation to be partitioned into its genotypic and environmental components. The proportion of genotypic to phenotypic variation is termed the broad sense heritability, and gives an indication of the predictability with which characters will be passed from parent to offspring (Breese 1972). From the results of the check survey it is apparent that there were marked differences in the heritability of different root characters (Table 6.7). Seedling root number was the most strongly inherited root character among the barley varieties selected for survey, followed in decreasing order by total root length, mean seminal root length and root diameter. The large heritability of total root length seems to be largely due to the large heritability of root number, as these characters are significantly correlated (Table 6.5). A first analysis also indicated that mean root diameter had a high heritability; however an examination of the results indicated that the heritability estimate was inflated by the inclusion of the atypically thick-rooted variety Ymer tetraploid (Tables 6.5 and 6.7).

The correlation of measurements of seedling root characters as measured on varieties included in the first and check surveys gives an additional indication of their heritability (Table 6.6). As with broad sense heritability the correlation coefficients for some root characters were inflated by the inclusion of Ymer tetraploid and so emphasis is placed on the analyses excluding this variety. The ranking of correlation coefficients for the seedling root characters fell in the same order as the estimates of broad sense heritabilities, thus giving further evidence of the strong heritability of seminal root number and seedling root length.

Although the expression of root characters is under some degree of genetic control, environmental factors may modify the translation of genotype to phenotype. If certain root characters are to be the subject of selection in plant breeding it is of some importance to determine the effects of specific environmental factors on the expression of these characters. This topic is discussed in the following paragraphs by reference both to evidence from the present surveys and to other published work.

Despite the relatively high broad sense heritability of seminal root number, the barley varieties in the check survey generally produced fewer roots than in the first survey and reductions were also found in seedling and mean seminal root length (Table 6.8). Growing conditions were the same in both surveys, the only difference between the surveys being that the seed used in the first survey was collected in 1975 and that for the check survey was collected in 1976. If the external environmental conditions were the same in both surveys, the phenotypic differences in root characters between surveys must have been due to differences in the internal environment of seed collected in 1975 and 1976 which affected genotypic expression.

The seed collected in 1976 was smaller than in 1975 (Table 6.9), perhaps due to the dry conditions in 1976 having an adverse effect on grain filling. It is interesting to note that the six row varieties showed a greater decrease in dry weight between years than the two row varieties which may indicate that there is a genotype environment interaction with respect to seed size.

TABLE 6.9 SEEDLING ROOT GROWTH OF BARLEY VARIETIES

Comparison of seed weight of varieties included in both the first and check surveys

| Variety | Type+ | 2 or 6 row | Mean Seed Weight (g x $10^{-2}$) | | |
|---|---|---|---|---|---|
| | | | First Survey A | Check Survey B | Difference (B-A) |
| Charlottetown 80 | V | 2 | 5.3 | 4.4 | - 0.9 |
| Valticky | V | 2 | 5.4 | 5.0 | - 0.4 |
| Varunda | V | 2 | 6.0 | 5.0 | - 1.0 |
| Ymer tetraploid | M | 2 | 6.5 | 6.8 | 0.3 |
| Akashinriki | V | 6 | 6.8 | 2.8 | - 4.0 |
| Ringve | V | 6 | 8.0 | 4.1 | - 3.9 |
| Sumiremochi | V | 6 | 7.3 | 3.9 | - 3.4 |
| Afghan R1395 | A | 6 | 8.8 | 5.0 | - 3.8 |
| Nepal NB 68A | A | 6 | 6.5 | 3.6 | - 2.9 |

+V = Modern variety, M = Unusual variant, A = Ancestral type

A number of workers have tried to establish a relationship between seed size and seedling vigour and root growth. Pope (1945) found that within a single barley variety (Wisconsin Barbless) there was a positive correlation between seed weight and seminal root number. Foltyn (1972) also found positive correlations of grain size with root number and root length with individual wheat varieties. However both Pope (1945) and Foltyn (1972), in surveys over a number of barley and wheat varieties, found that seed size was not correlated with the expression of seedling root characteristics. This suggests that the response to seed size depends on genotype. In the context of the present experiments it seems unlikely that the expression of root characteristics was directly influenced by seed size as, although there was a correlation of the seedling root characters of varieties included in both surveys, seed weight showed no such correlation (Table 6.6). However variations in seed weight may be indicative of changes in the internal environment of the seed which have direct effects on the expression of seminal root characters.

Bremner et al (1963) suggested that seedling root characters were affected by seed weight because of the linear relationship between seed and endosperm weight. Before the exposure of the first leaf of a seedling to light, growth is dependent on the reserve carbohydrates in the endosperm, more than half of which are used by the seminal roots (Williams 1960). Robertson et al (1979) extended this hypothesis by suggesting that the control of seedling root numbers may also be moderated by hormones controlling the mobilisation and distribution of the seeds food reserves. Thus the expression of seminal root characters may be influenced by the amount and speed of mobilisation of reserve carbohydrates.

Changes in seed weight are frequently correlated with changes in the concentration of one or more seed constituents which may directly influence the expression of seedling root characters. Bulsani and Warner (1980) reported that the percentage protein content of wheat seeds was positively correlated with seed weight; however this must be contrasted with the observation that seeds of the same weight may have different protein contents (Ries and Everson 1973). In studies in oats (Schweizer and Ries 1969), wheat (Ries and Everson 1973; Bulsani and Warner 1980) and barley (Welch 1977) seedling vigour was found to be correlated with seed protein content. Although seedling vigour is only an indicator of seedling root development, it would seem that seed protein content may be positively correlated with root development. Ching and Rynd (1978) suggested that the high total ribosome and particularly polysome content observed in high protein seeds may be responsible for the rapid growth and high yield of plants produced from these seeds. Again the relationships are empirical and as Welch (1977) pointed out, the husbandry techniques used to increase grain protein concentration may also increase the concentration of mineral nutrients in the seed which themselves may influence root growth.

Thus although the present experiments suggest that the expression of seminal root characters may be related to seed weight, root growth may in fact have been influenced by variation in one or more factors in the internal seed environment which are to some degree correlated with seed weight.

In the first survey an overall comparison among varieties showed a significant correlation between root length and germination percentage (Table 6.4). Most varieties had germination percentages greater than 75% (i.e. 19 out of 25 seeds germinated after imbibition for 72 hours); however some varieties germinated poorly and seeds of these varieties tended to produce relatively small root systems (Figure 6.2(a)). This result may indicate that seeds with poor viability as envinced by their poor germination may produce smaller root systems. However it may also be suggested that some varieties inherently have poor germination and root growth and that a similar relationship between root length and germination percentage would not be found in all varieties. Further tests would be necessary to resolve this question. In practice however this relationship may be unimportant as it may be expected that field sown commercial varieties would have high germination percentages and the present experiments give no evidence of a relationship between germination percentage and root growth when germination percentage is in the higher ranges.

It should also be noted that the expression of seedling root characters may be influenced by the external environment. Taylor and McCall (1936) found that the number of seminal roots produced by the wheat variety 'Hard Federation' was influenced by seedbed temperature and depth of seeding. In a later study O'Brien (1978) found that the expression of root characters of the wheat cultivars Israel M68 and Olympic were different in sand fractions of different particle sizes. O'Brien (1978) also found a significant interaction of cultivar with environment; Israel M68 had a greater root dry weight than Olympic when grown in solution culture and in 2 to 3 mm and 1 to 2 mm sand fractions whereas Olympic had the greater root dry weight when grown in 0.5 to 1 mm and $< 0.5$ mm sand fractions.

Thus although the barley varieties in the present survey were found to produce certain numbers of seminal roots, it is clear that the expression of this and other seminal root characters can be markedly influenced by the environment. Furthermore there is some evidence that the response to environment may vary among genotypes and so it is possible that the ranking of varieties with respect to root characteristics may change in different environments. From this it can be seen that any survey of seminal root phenotype should be made under carefully controlled conditions perhaps similar to those adopted in the present survey. The survey system used in the present investigation may prove convenient as it allows the selection of plants with desirable root characters early in their growth. Selected plants could be easily transferred to other growing media to grow to maturity.

Although the range of expression of seedling characters in barley is of some academic interest the question must be asked; of what benefit may this information be in breeding high yielding varieties? Ideally a plants root system should explore the soil and exploit its reserves of water and nutrients in such a way that the plant produces the maximum harvestable yield possible in a given environment. The optimum root system for each crop and method of cultivation thus depends on knowledge of the relationship between different root systems and crop yield. The information so far available is empirical and based on the results of relatively few experiments. Sallans (1942), working with spring wheat in Canada, found that wheat plants with the greatest number of seminal roots tended to produce the greatest yield of grain. Kandaurov and Movchan (1970), studying durum wheat cultivars, also found a positive relationship between the number of primary roots and yield.

Russell (1971) suggested that the speed at which roots attain the minimum size necessary for the uninterrupted supply of water and nutrients may determine the yielding capacity of a crop. Thus seedlings with greater root vigour (as measured by the rate of increase in root length) are likely to produce greater yields. This suggestion is supported by the results of Kaufman and Guitard (1967) who found that in cereals vigorous seedlings produced greater yields. Workers have usually studied seedling vigour in relation to seed characters although Evans and Bhatt (1977) reported genotypic differences in seedling vigour in wheat. However no work has directly studied the relationship of root vigour (as defined above) to crop yield.

The type of root system required to achieve maximum yields in favourable conditions may be different from that required in adverse conditions. A number of workers have attempted to characterise the type of root system necessary to enable crops to produce maximum yields when water supply is restricted. Hurd (1968) and Danil'chuk (1970) suggested that, where water is available at depth, wheat varieties with roots which rapidly grew down and proliferated in the deeper soil layers were more resistant to drought. As nodal roots tend to remain in the upper soil layers (Weaver 1926; Briggs 1978) in the conditions described above the crop is presumably largely dependent on the activity of the seminal root system. It is not known whether the vigour of seedling roots is related to depth of rooting and further information on this topic would be useful.

Passioura (1974) also agreed that deep rooting crops may be at an advantage where the water content of deep soil layers is recharged annually. However where this does not occur he suggested that cereal yields could be maximised by conserving soil water during vegetative growth so that more water is available during the drought sensitive grain filling phase. Passioura (1974) suggested that this water conservation could be achieved by reducing the number of seminal roots, although this may conflict with the need for a much branched root system for nutrient uptake (O'Brien 1979).

From the present survey and other work it is evident that there is considerable genotypic variability in root system characters of both seedling and mature plants. The results of the present survey gives information which may help in selecting varieties to be used either in breeding or in studies of the relationship between root system characters and crop growth and yield.

# PART II

# LABORATORY EXPERIMENTS

## SECTION 7

## RESPONSE OF SELECTED BARLEY VARIETIES TO SOIL COMPACTION

# 7. RESPONSE OF SELECTED BARLEY VARIETIES TO SOIL COMPACTION

## 7.1 Introduction

In 1978 experiments were made in which barley varieties were grown in soil compacted to varying dry bulk densities. Barley varieties with diverse seminal root characters were selected for the experiments from the varieties previously studied (see Section 6). It was hoped that these experiments would give an indication of which, if any, characteristics of the seedling root system would be advantageous when growing in compact soil.

Three experiments were made:

1. Response of the barley variety Georgie to soil compaction.

   In field experiments it has been concluded that the slower early growth of direct-drilled barley was due to mechanical impedance in the more compact soil found after direct drilling (see Section 1). This preliminary study was used to test the experimental technique and to characterise the effect of soil compaction on seedling root and shoot growth.

2. Response of the barley varieties Ymer tetraploid and Ringve to soil compaction.

   The ability of a root to penetrate compact soil may depend on its diameter. Barley (1968) found that the fairly thick roots of two grasses <u>Phalaris tuberosa</u> and <u>Paspalum dilatatum</u> could penetrate soil clods that the thin roots of perennial ryegrass and cocksfoot were unable to. On the other hand as soil is compacted there is often a particular reduction in the proportion of pores large enough to allow unimpeded extension of roots (see Section 5); a variety with fine roots may be able to explore the smaller pores of compact soil more easily than a variety with coarse roots.

   In this experiment the growth of barley varieties with relatively fine (Ringve) and coarse (Ymer tetraploid) roots were compared at three soil compaction levels.

3. Response of the barley varieties Varunda and Sumiremochi to soil compaction.

   In this experiment the growth of barley varieties with many (Varunda) and few (Sumiremochi) seminal roots were compared at three soil compaction levels.

## 7.2 Methods

### 7.2.1 Soil Preparation and Compaction

The soil used in the experiments was a clay loam of the Macmerry Soil Series (Soil Survey of Scotland) with the physical and chemical characteristics shown in Table 7.1. All soil used in the experiment was collected before the start of the experimental programme.

TABLE 7.1 PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOIL USED IN ALL COMPACTION EXPERIMENTS

| | | | |
|---|---|---|---|
| Soil Series (Soil Survey of Scotland) | | MacMerry | |
| Soil texture | | Clay Loam | |
| Particle size distribution (% by weight of peroxide treated soil) | Sand | > 63 μm | 49% |
| | Silt | 63-2 μm | 32% |
| | Clay | < 2 μm | 19% |
| pH | 6.4 | | |
| Potassium (mg/kg soil) | 184 | | |
| Phosphorus (mg/kg soil) | 5.2 | | |
| Magnesium (mg/kg soil) | 230 | | |

In preparation for compaction the soil was air-dried at $20^{\circ}C$ to 3-4% moisture content. The soil was then bulked and thoroughly mixed before being randomly divided into samples for each experiment.

A sample of soil was used to determine the dry bulk density attained by soil of different moisture contents when compacted by a standard method (BRITISH STANDARD 1377, see Appendix 1) using a Proctor compaction machine (Plate 7.1). In this method the soil is compacted by a 2.5 kg rammer falling through a height of 30.5 cm. The parabolic curve of soil dry bulk density attained at varying soil moisture contents (Figure 7.1) was then used to predict the soil moisture content required to produce pots containing soil compacted to specific dry bulk densities.

In order to produce the pots of compact soil used in the experiments the operation of the Proctor compaction machine was slightly modified. The metal mould normally used to hold the soil under test was replaced by plastic tubes of the same height (11.6 cm) and diameter (10.2 cm) as the mould (Plate 7.2).

### 7.2.2 Soil Water Potential

The pots containing compacted soil were transferred to a sand box and allowed to equilibrate for several days to the water potential at which the soil was kept during the experiments (pF 1.7, - 0.05 bars). The use of the sand box allowed the soil in all pots to be maintained at the same water potential thus minimising any interaction of water potential with the effect of soil bulk density on mechanical impedance (see Section 5).

The sand box was constructed following the design principles of Harst and Stakman (1965). The box was 90 cm square with sides 15 cm high. Drainage was provided by a network of nylon tubes connected to a levelling bottle. The nylon tubing was perforated on the underside and wrapped with hydrophilic nylon cloth to aid in excluding silt and fine sand from the tubing. The nylon tubing was covered with 3 layers of sand. The top layer with 80% of its particles in the range 30-70 μm maintained the required water potential. The next two layers acted as filters preventing the fine sand being washed into the drainage tubes. The lower layer completely covered the drainage tubes and comprised 1 to 5 mm sand particles; the middle layer consisted of particles 0.5 to 1 mm in diameter. The sand surface was covered with fine mesh nylon cloth to prevent contamination of the fine sand with soil.

### 7.2.3 Seedling Germination and Growth

In preparation for each experiment over a 100 seeds of each variety used were surface sterilised and pregerminated following the procedures described in Section 6.2. Seeds were germinated for 48 hours and then seedlings which appeared to be similar, with radicles 2 mm long were selected for use in the experiments. The selected seedlings were transferred to paper tubes (2 cm high, 1 cm diameter) containing vermiculite; these tubes were then placed on top of the pots containing compacted soil (see Plate 7.3). The seedlings were grown following this procedure after preliminary investigations had shown that:

1. Seeds planted in the soil during compaction suffered mechanical damage and their emergence was poor.
2. Making holes in the compacted soil in which to plant seeds produced cracks in the soil along which roots grew preferentially.

The use of the paper pots had the additional advantage that it allowed the seedlings used in the experiment to be selected for uniformity and so helped to minimise experimental error.

The experiments were made in the north facing compartment of a glasshouse on Bush Estate, Penicuik, Midlothian. Each experiment lasted 14 days by which time the seedlings had two leaves (see Plate 7.3). During each experiment the natural light was supplemented using Mercury Vapour Lamps which provided 70 watts $m^{-2}$ for 12 hours each day. The air temperature averaged $10^{o}C$ during the trials and ranged from 5 to $20^{o}C$.

### 7.2.4 Analysis of Seedling Growth

At harvest the shoots were removed and the height of the first and second leaves were measured. The total leaf area was measured using a Hyashi Denko Type AAM-5 Leaf Area Meter. The fresh and dry weights of the shoots were determined.

The soil pots were dried at room temperature for two days to allow slight shrinkage of the soil which allowed the removal of the intact soil cores from the plastic pots. The soil cores were then soaked in water for 30 minutes and then the root systems were washed out using a gentle water spray. Using this method complete root systems were obtained (Plate 7.5) and careful examination of soil residues led to no further roots being discovered. The root systems were then soaked overnight in 1% sodium pyrophosphate solution after which any soil still adhering to them was easily washed off. The root systems were dissected into seminal root axes and lateral roots and all subsequent measurements were performed separately on these two components of the root system. The root samples were frozen if they required storage before being measured.

In order to measure root diameter the samples of root were distributed randomly on a wetted glass plate. The plate was then laid on a paper sheet marked with parallel lines at 1 cm intervals. The lines were used as guides along which a microscope was tracked and the diameter of roots crossing the lines were measured (50 per sample); this procedure ensured that a random selection of roots were measured. The diameters were measured using a Wild microscope, fitted with an eyepiece graticule, at 50x magnification.

Where possible the length of roots in each sample were then measured using a machine built following the design of Rowse and Phillips (1974) at the University of Nottingham's Applied Science Faculty Workshops. Its functioning was subsequently improved by Dr R Milne of the Institute of Terrestrial Ecology, Bush Estate with modifications increasing the precision of the optical detection system and associated electronics coupled with improvements to the mechanical drive. The machine operates on Newman's (1966) line intersect principle.

The accuracy of the instrument was tested by using it to measure known lengths of fine wire and also by measuring roots previously measured by hand (Figure 7.2). It was found that the machine gave less accurate estimates if the length of root in a sample was less than 100 cm; so all samples with root samples with a total length less than about 100 cm were measured directly. Roots measured using the machine were dried onto the glass plate on which they had been laid out for the diameter measurements. This was necessary as the detection system of the machine was found to respond to a glass/air/water interface which led to overestimation of the lengths of roots in wet samples. After the diameters and lengths of roots had been measured they were dried and weighed.

#### 7.2.5 Experimental Designs

Each experiment had 36 plots with 6 replicates of each treatment laid out in a 6 x 6 latin square. In the first experiment the growth of the barley variety Georgie was examined at 6 levels of soil bulk density. In the subsequent experiments a factorial design was used to compare the growth of two barley varieties with contrasting root characters under 3 levels of soil bulk density.

A guard row of pots was laid round the outside of the experiment (Plate 7.4) to help in maintaining a uniform environment across the experimental area.

## 7.3 Results

The results from the three compaction experiments are given in the following sections. In the tables the letters V and C refer to treatment comparisons; V between varieties, C between compaction levels. Interactions are indicated by a combination of these two letters. Asterisks refer to the level of significance of a difference *** ($P < .001$) ** ($P < .01$) * ($P < .05$) and ns (no statistical significance).

### 7.3.1 Response of the Barley Variety Georgie to Soil Compaction

#### 7.3.1.1 Seminal Root Growth (Table 7.2, Figure 7.3)

Increased soil compaction had no effect on seminal root length, although visual observation had shown that at higher compaction levels root growth was restricted to the soil near the surface. As compaction increased seminal root diameter increased and this led to an increase in seminal root volume.

7.3.1.2 Lateral Root Growth (Table 7.3, Figure 7.3)

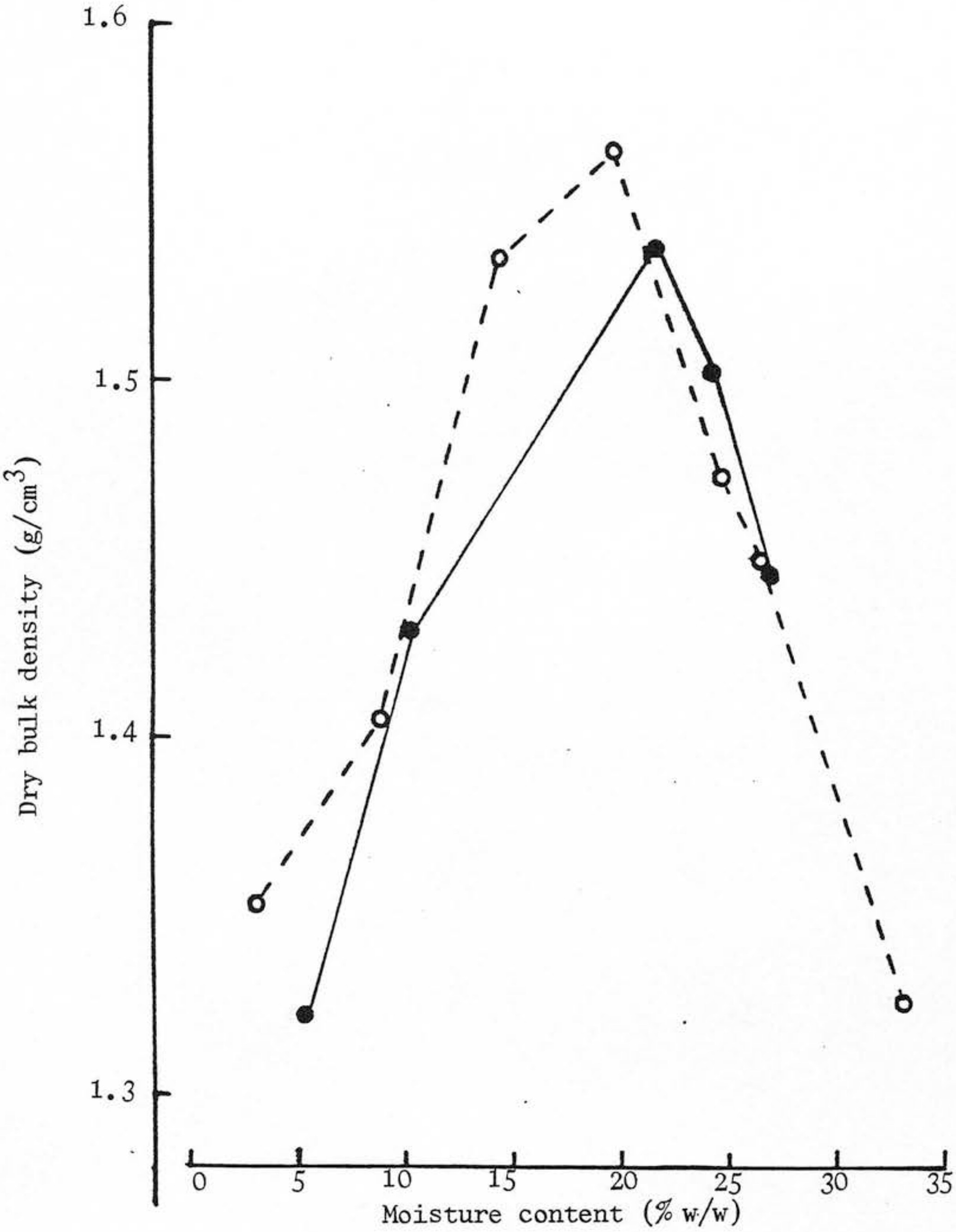
In contrast to the seminal roots, the lateral root length was reduced by compaction although the effect was not statistically significant. As compaction increased lateral root diameter increased. As with seminal root diameter, the increase in lateral root diameter showed a strong linear correlation with compaction level.

7.3.1.3 Dry Matter Production (Table 7.4, Figure 7.4)

As soil compaction increased a slight decrease in shoot dry weight was accompanied by an increase in both seminal and lateral root dry weight. This led to a significant decrease in shoot/root ratio with increasing compaction. Both the increase in seminal root dry weight and the decrease in shoot/root ratio showed a strong linear correlation with soil compaction level.

7.3.1.4 Leaf Length and Area (Table 7.5)

Leaf area decreased slightly as soil compaction increased, although this effect was not statistically significant. Leaf length was not affected by soil compaction.




● results from 3/5/77

o results from 10/5/77

Figure 7.1 Relationship of dry bulk density to moisture content of MacMerry clay loam when subjected to standard compaction.

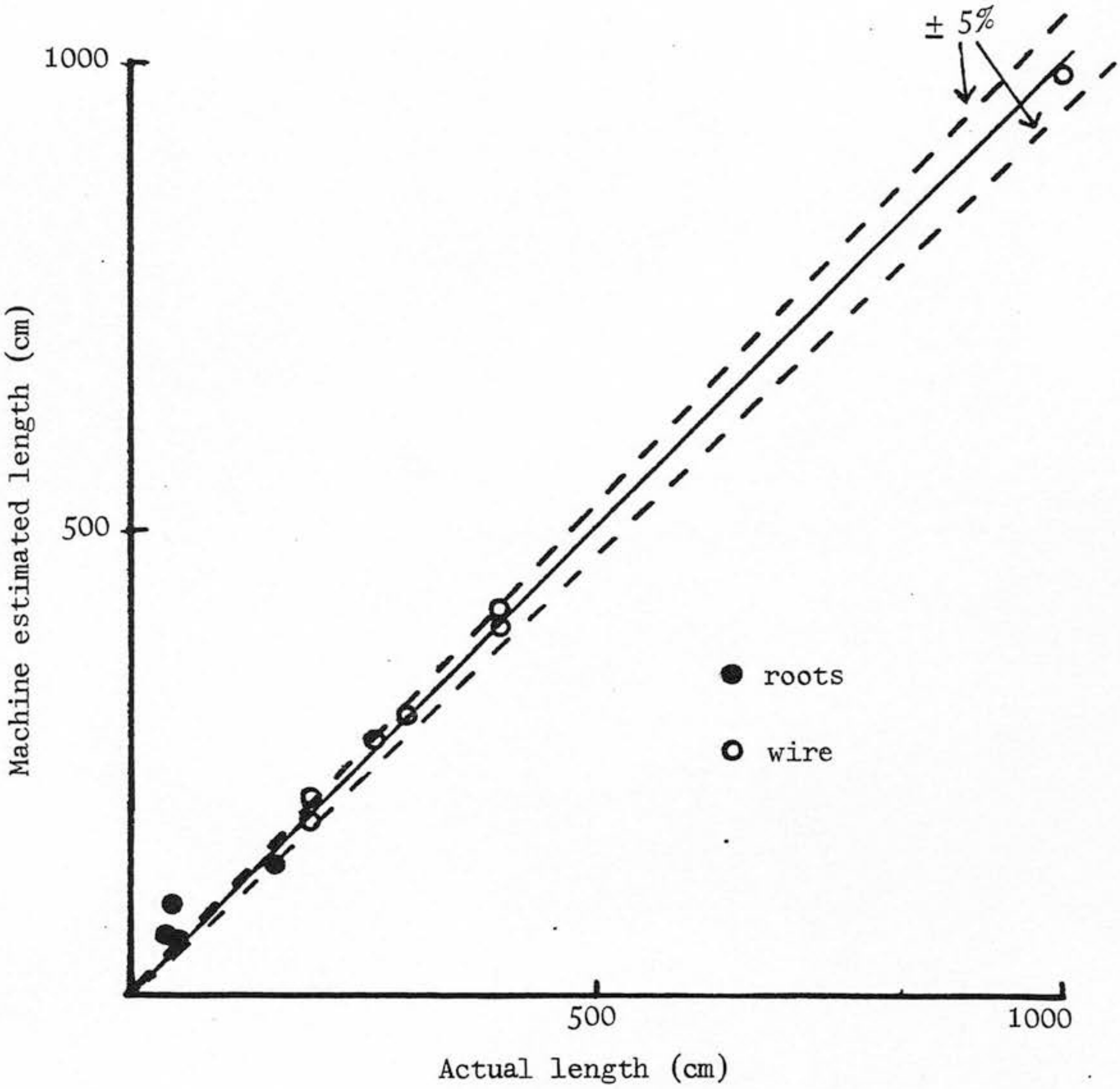



Figure 7.2 Machine estimation of known lengths of wire and roots.

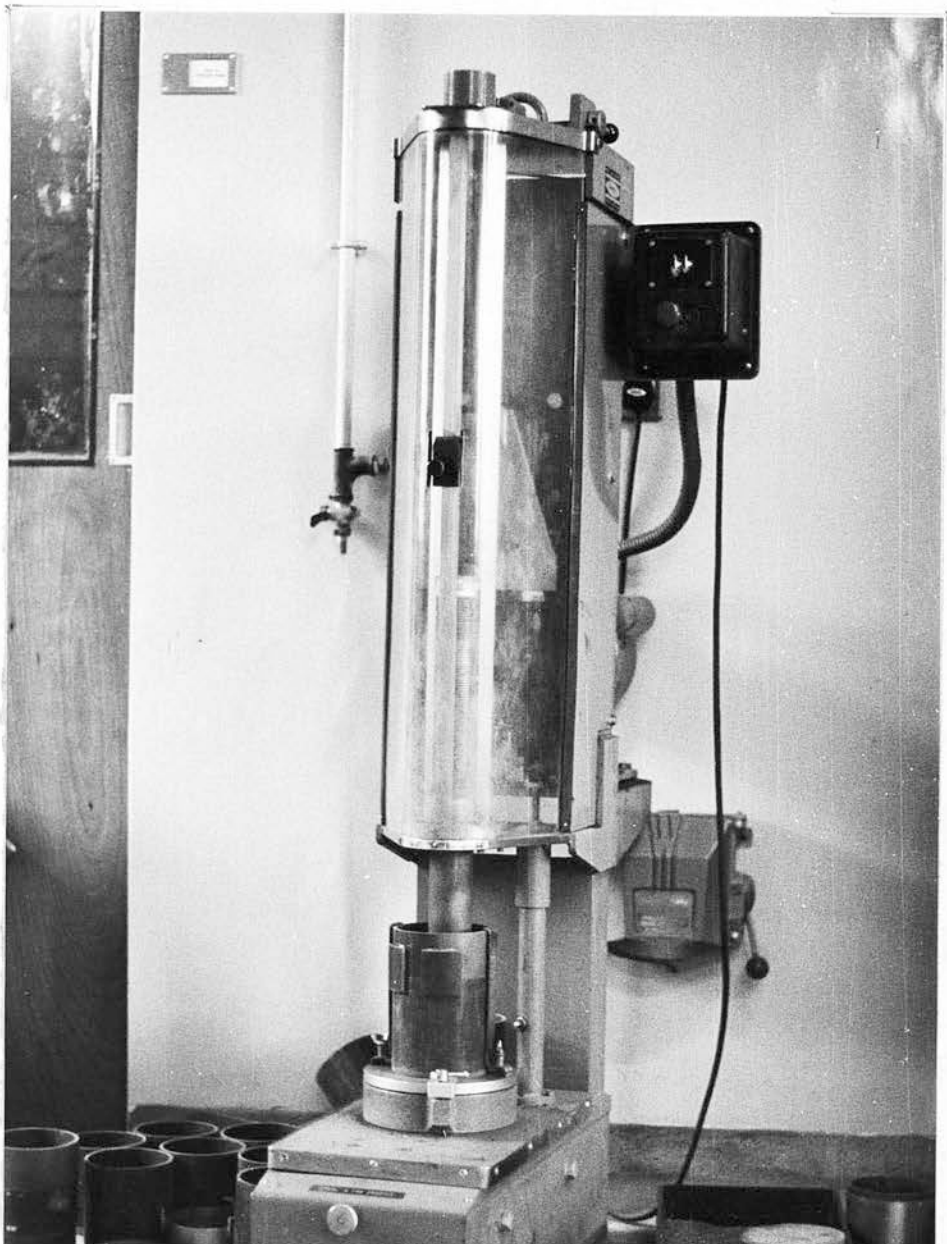


Plate 7.1 Proctor soil compaction machine


Plate 7.2 Plastic pot containing soil under compaction

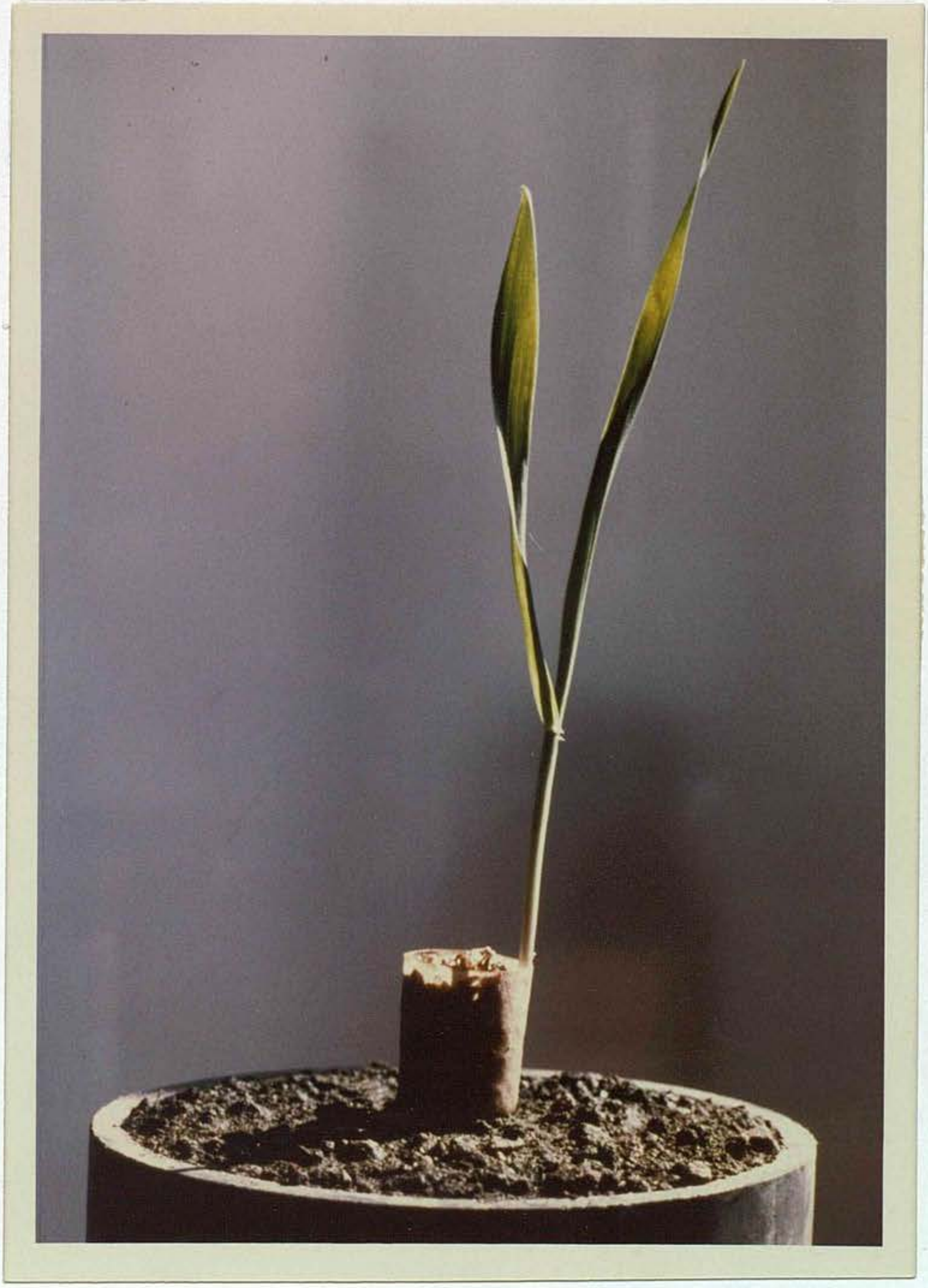


Plate 7.3 Barley seedling after 14 days growth in soil compaction pot.

Plate 7.4 Compaction experiment laid out on moisture tension table in the glasshouse.

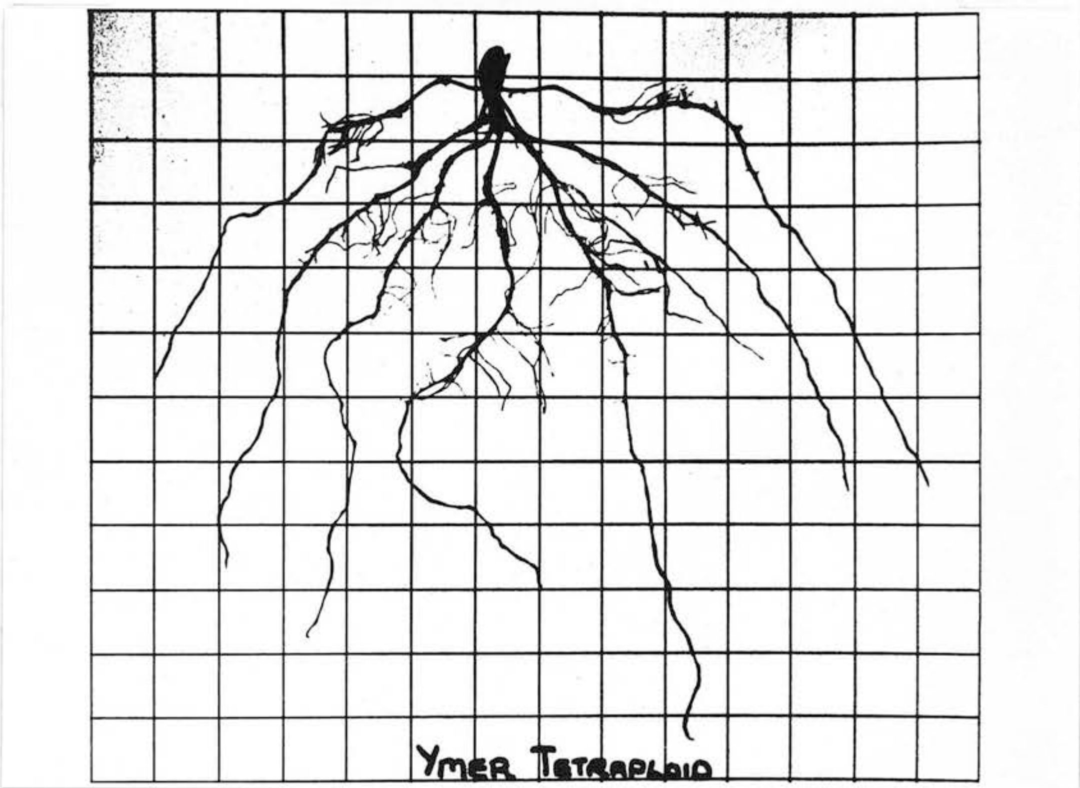



Plate 7.5 Seedling root system of Ymer tetraploid after 14 days growth in soil compacted to 1.43 g/cm$^3$ dry bulk density.

TABLE 7.2 RESPONSE OF THE BARLEY VARIETY GEORGIE TO SOIL COMPACTION

Seminal Root Growth

| | Soil compaction (dry bulk density $g/cm^3$) | Root length (cm) | Root diameter (mm) | Root volume ($cm^3$) |
|---|---|---|---|---|
| | 1.43 | 50.7 | 0.37 | 0.0541 |
| | 1.47 | 45.0 | 0.38 | 0.0511 |
| | 1.48 | 46.6 | 0.39 | 0.0572 |
| | 1.51 | 44.8 | 0.40 | 0.0569 |
| | 1.52 | 46.2 | 0.41 | 0.0617 |
| | 1.56 | 48.3 | 0.44 | 0.0738 |
| Statistical significance | | ns | * | ns |
| SED | | 4.04 | 0.019 | 0.00782 |
| Linear regression coefficient | | -15.0 ±28.3 | 0.055 ±0.0134 | 0.152 ±0.0549 |
| Statistical significance of linear regression | | ns | *** | * |

TABLE 7.3 RESPONSE OF THE BARLEY VARIETY GEORGIE TO SOIL COMPACTION

Lateral Root Growth

| | Soil compaction (dry bulk density $g/cm^3$) | Root length (cm) | Root diameter (mm) | Root volume ($cm^3$) |
|---|---|---|---|---|
| | 1.43 | 252 | 0.15 | 0.0455 |
| | 1.47 | 233 | 0.17 | 0.0501 |
| | 1.48 | 220 | 0.18 | 0.0551 |
| | 1.51 | 179 | 0.18 | 0.0447 |
| | 1.52 | 170 | 0.18 | 0.0439 |
| | 1.56 | 194 | 0.20 | 0.0613 |
| Statistical significance | | ns | ** | ns |
| SED | | 35.1 | 0.011 | 0.00878 |
| Linear regression coefficient | | -586 ±246.6 | 0.0384 ±0.0078 | 0.071 ±0.616 |
| Statistical significance of linear regression | | * | *** | ns |

TABLE 7.4 RESPONSE OF THE BARLEY VARIETY GEORGIE TO SOIL COMPACTION

Dry Matter Production

| | Soil compaction (dry bulk density $g/cm^3$) | Shoot dry weight (g) | Seminal root dry weight (g) | Lateral root dry weight (g) | Shoot/ root ratio |
|---|---|---|---|---|---|
| | 1.43 | 0.060 | 0.0046 | 0.0074 | 5.05 |
| | 1.47 | 0.058 | 0.0055 | 0.0074 | 4.53 |
| | 1.48 | 0.064 | 0.0063 | 0.0088 | 4.40 |
| | 1.51 | 0.060 | 0.0076 | 0.0072 | 4.23 |
| | 1.52 | 0.055 | 0.0086 | 0.0077 | 3.45 |
| | 1.56 | 0.052 | 0.0095 | 0.0105 | 2.63 |
| Statistical significance | | ns | ** | ns | *** |
| SED | | 0.0044 | 0.00106 | 0.00141 | 0.383 |
| Linear regression coefficient | | -0.065 ±0.0309 | 0.0409 ±0.00741 | 0.0182 ±0.00988 | -18.4 ± 2.69 |
| Statistical significance of linear regression | | * | *** | ns | *** |

TABLE 7.5 RESPONSE OF THE BARLEY VARIETY GEORGIE TO SOIL COMPACTION

Leaf Length and Area

| Soil compaction (dry bulk density $g/cm^3$) | Length 1st leaf (cm) | Length 2nd leaf (cm) | Leaf area ($cm^2$) |
|---|---|---|---|
| 1.43 | 28 | 17 | 28 |
| 1.47 | 27 | 18 | 26 |
| 1.48 | 28 | 18 | 29 |
| 1.51 | 26 | 17 | 27 |
| 1.52 | 26 | 18 | 26 |
| 1.56 | 26 | 18 | 24 |
| Statistical significance | ns | ns | ns |
| SED | 1.3 | 0.8 | 2.2 |

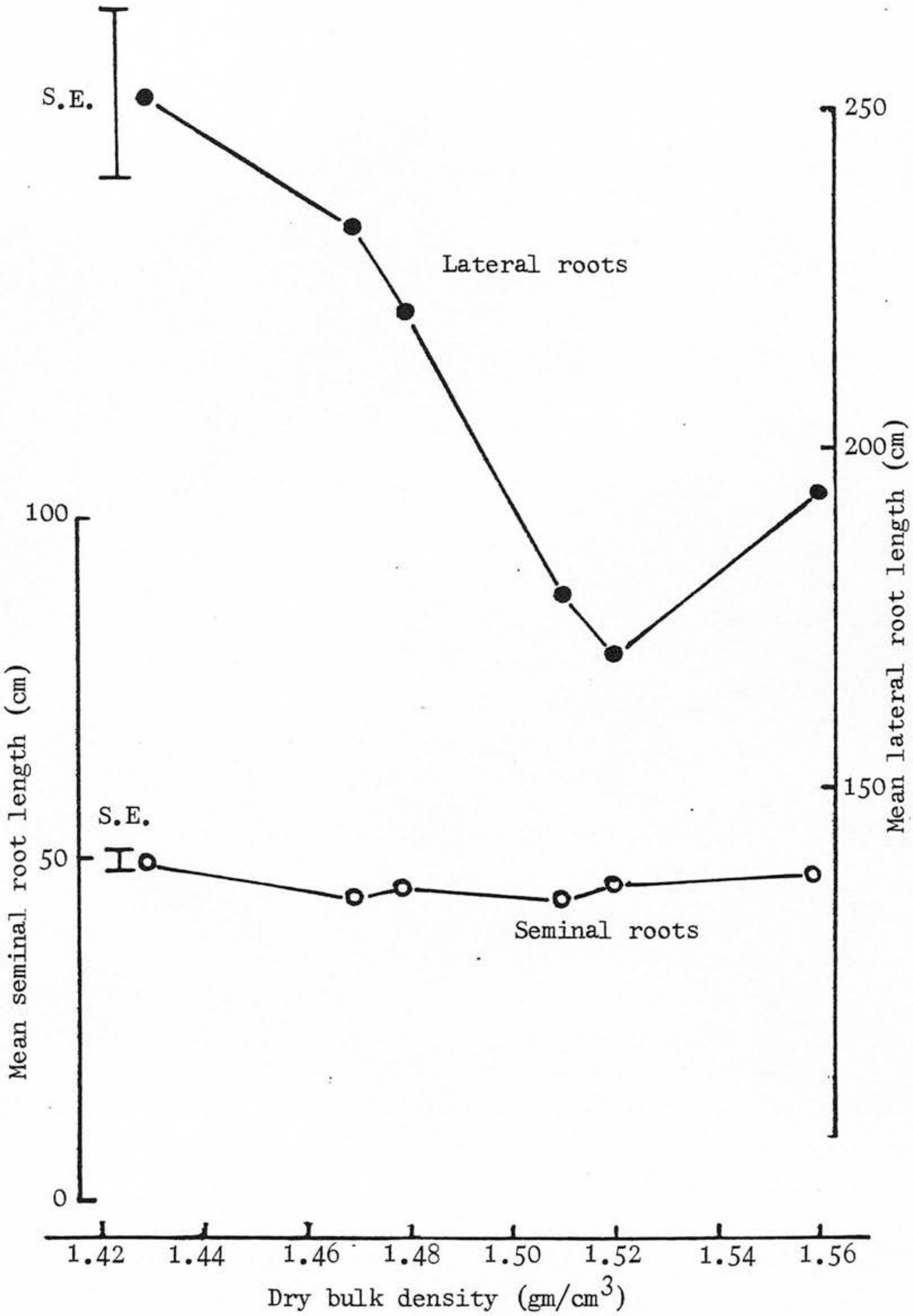



Figure 7.3 Effect of soil bulk density on seminal and lateral root length of barley variety Georgie.

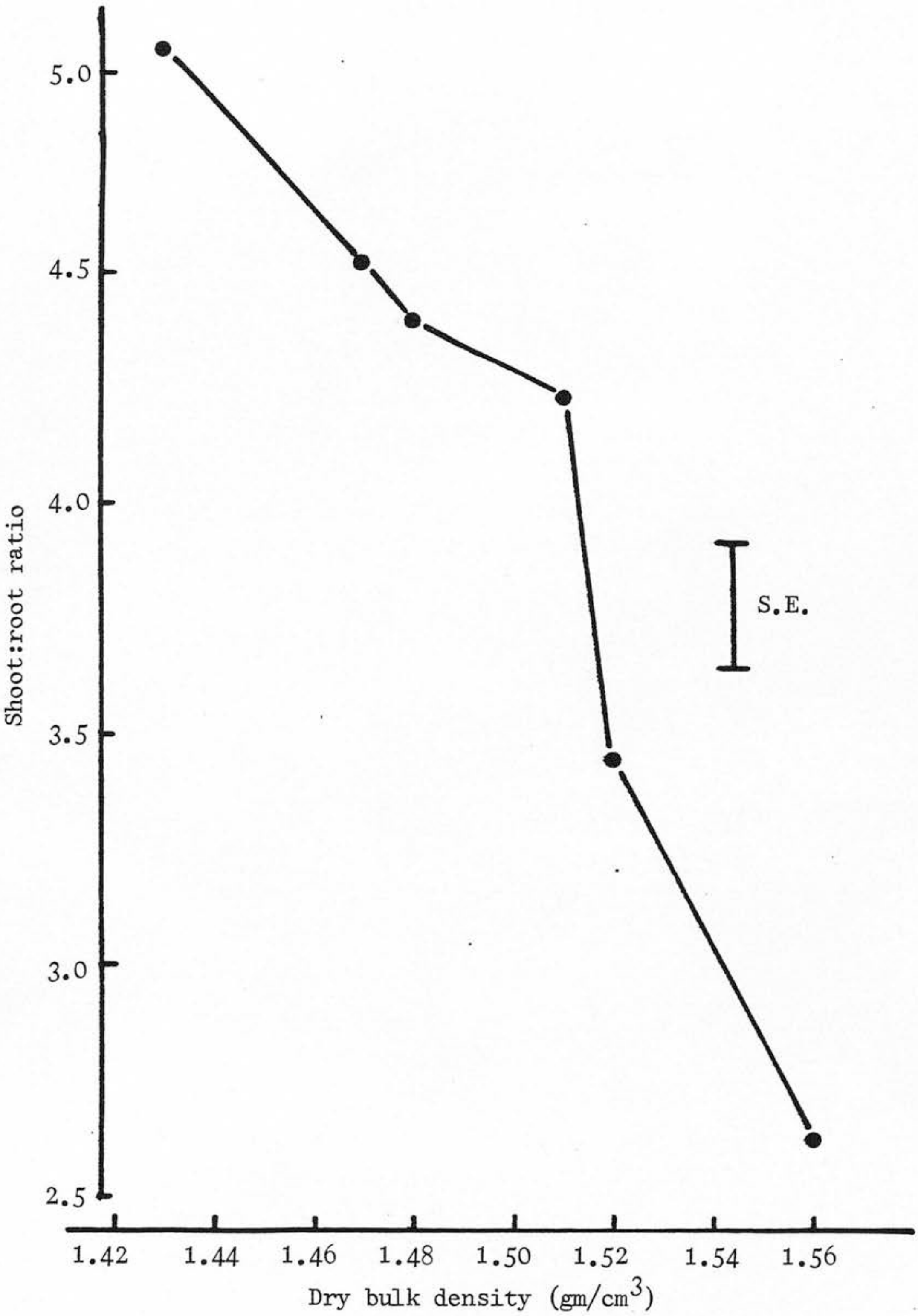



Figure 7.4 Effect of soil compaction on shoot:root ratio of barley variety Georgie.

## 7.3.2 Response of the Barley Varieties Ringve and Ymer tetraploid to Soil Compaction

### 7.3.2.1 Seminal Root Growth (Table 7.6)

Seminal root length, diameter and volume differed between varieties. Ymer tetraploid had a greater root diameter than Ringve and this meant that despite its smaller root length, Ymer tetraploid had the greater root volume. Seminal root length decreased and root diameter increased in both varieties as soil compaction increased.

### 7.3.2.2 Lateral Root Growth (Table 7.7, Figure 7.5)

As with seminal roots there were marked varietal differences in lateral root growth. In this case the thickness of the lateral roots of Ymer tetraploid did not compensate for their much shorter length and so Ymer tetraploid had a smaller root volume than Ringve.

Both varieties reacted similarly to compaction in that root length decreased and root diameter increased as soil compaction increased. Although there was a significant variety/cultivation interaction for lateral root length further analysis of the results showed that although the actual decrease in root length is much greater for Ringve, as compaction increased the lateral root length of both varieties decreased by 40%.

### 7.3.2.3 Dry Matter Production (Table 7.8)

The dry weight of both varieties decreased as compaction increased although this decrease was more marked for Ymer tetraploid. Also both varieties showed a decrease in shoot/root ratio although in this case the decrease was greater for Ringve than Ymer tetraploid.

### 7.3.2.4 Leaf Length and Area (Table 7.9)

As soil compaction increased both varieties showed a similar decrease in total leaf area and length of the second leaf; the length of the first leaf was not significantly affected by compaction. There were significant varietal differences in all three shoot characters.

TABLE 7.6 RESPONSE OF THE BARLEY VARIETIES RINGVE AND YMER TETRAPLOID TO SOIL COMPACTION

Seminal Root Growth

| Soil compaction (dry bulk density (g/cm$^3$) | | Root length (cm) | | Root diameter (mm) | | Root volume (cm$^3$) | |
|---|---|---|---|---|---|---|---|
| | | Ringve | Ymer tetra-ploid | Ringve | Ymer tetra-ploid | Ringve | Ymer tetra-ploid |
| 1.43 | | 66.1 | 54.5 | 0.46 | 0.62 | 0.1113 | 0.1643 |
| 1.49 | | 51.1 | 44.8 | 0.48 | 0.69 | 0.0939 | 0.1650 |
| 1.53 | | 57.6 | 37.3 | 0.47 | 0.66 | 0.1011 | 0.1276 |
| Statistical significance | C | * | | ns | | ns | |
| | V | ** | | *** | | *** | |
| | CxV | ns | | ns | | ns | |
| SED | C | 4.25 | | 0.019 | | 0.01289 | |
| | V | 3.47 | | 0.016 | | 0.01052 | |
| | CxV | 6.01 | | 0.027 | | 0.01822 | |

TABLE 7.7 RESPONSE OF THE BARLEY VARIETIES RINGVE AND YMER TETRAPLOID TO SOIL COMPACTION

Lateral Root Growth

| Soil compaction (dry bulk density g/cm$^3$) | | Root length (cm) | | Root diameter (mm) | | Root volume (cm$^3$) | |
|---|---|---|---|---|---|---|---|
| | | Ringve | Ymer tetra-ploid | Ringve | Ymer tetra-ploid | Ringve | Ymer tetra-ploid |
| 1.43 | | 290.2 | 60.3 | 0.17 | 0.28 | 0.066 | 0.035 |
| 1.49 | | 205.2 | 49.0 | 0.19 | 0.28 | 0.056 | 0.030 |
| 1.53 | | 156.3 | 35.2 | 0.21 | 0.32 | 0.051 | 0.029 |
| Statistical significance | C | *** | | * | | ns | |
| | V | *** | | *** | | *** | |
| | CxV | *** | | ns | | ns | |
| SED | C | 15.34 | | 0.013 | | 0.0064 | |
| | V | 12.53 | | 0.010 | | 0.0053 | |
| | CxV | 21.70 | | 0.018 | | 0.0091 | |

TABLE 7.8(A) RESPONSE OF THE BARLEY VARIETIES RINGVE AND YMER TETRAPLOID TO SOIL COMPACTION

Dry Matter Production

| Soil compaction (dry bulk density g/cm$^3$) | | Total dry weight (g) | | Shoot/root ratio | |
|---|---|---|---|---|---|
| | | Ringve | Ymer tetraploid | Ringve | Ymer tetraploid |
| 1.43 | | 0.0626 | 0.0534 | 5.29 | 4.84 |
| 1.49 | | 0.0591 | 0.0534 | 6.09 | 4.55 |
| 1.53 | | 0.0600 | 0.0452 | 4.38 | 4.26 |
| Statistical significance | C | * | | * | |
| | V | ns | | * | |
| | CxV | ns | | ns | |
| SED | C | 0.00444 | | 0.362 | |
| | V | 0.00362 | | 0.296 | |
| | CxV | 0.00628 | | 0.512 | |

TABLE 7.8(B) RESPONSE OF THE BARLEY VARIETIES RINGVE AND YMER TETRAPLOID TO SOIL COMPACTION

Dry Matter Production

| Soil Compaction (Dry Bulk Density g/cm$^3$) | | Shoot Dry Weight (g) | | Seminal Root Dry Weight (g) | | Lateral Root Dry Weight (g) | |
|---|---|---|---|---|---|---|---|
| | | Ringve | Ymer tetra-ploid | Ringve | Ymer tetra-ploid | Ringve | Ymer tetra-ploid |
| 1.43 | | 0.053 | 0.044 | 0.0063 | 0.0076 | 0.0038 | 0.0017 |
| 1.49 | | 0.051 | 0.044 | 0.0051 | 0.0079 | 0.0034 | 0.0019 |
| 1.53 | | 0.049 | 0.036 | 0.0075 | 0.0075 | 0.0039 | 0.0015 |
| Statistical significance | C | ns | | ns | | ns | |
| | V | ** | | * | | *** | |
| | CxV | ns | | ns | | ns | |
| SED | C | 0.0088 | | 0.00075 | | 0.00035 | |
| | V | 0.0031 | | 0.00062 | | 0.00028 | |
| | CxV | 0.0053 | | 0.00107 | | 0.00049 | |

TABLE 7.9 RESPONSE OF THE BARLEY VARIETIES RINGVE AND YMER TETRAPLOID TO SOIL COMPACTION

Leaf Length and Area

| Soil Compaction (Dry Bulk Density $g/cm^3$) | | Length 1st Leaf (cm) | | Length 2nd Leaf (cm) | | Leaf Area ($cm^2$) | |
|---|---|---|---|---|---|---|---|
| | | Ringve | Ymer tetraploid | Ringve | Ymer tetraploid | Ringve | Ymer tetraploid |
| 1.43 | | 18 | 22 | 24 | 16 | 27 | 17 |
| 1.49 | | 19 | 21 | 22 | 14 | 25 | 16 |
| 1.53 | | 19 | 20 | 21 | 13 | 23 | 14 |
| Statistical significance | C | ns | | * | | ns | |
| | V | ** | | *** | | *** | |
| | CxV | ns | | ns | | ns | |
| SED | C | 0.8 | | 1.1 | | 1.4 | |
| | V | 0.7 | | 0.9 | | 1.2 | |
| | CxV | 1.2 | | 1.5 | | 2.0 | |

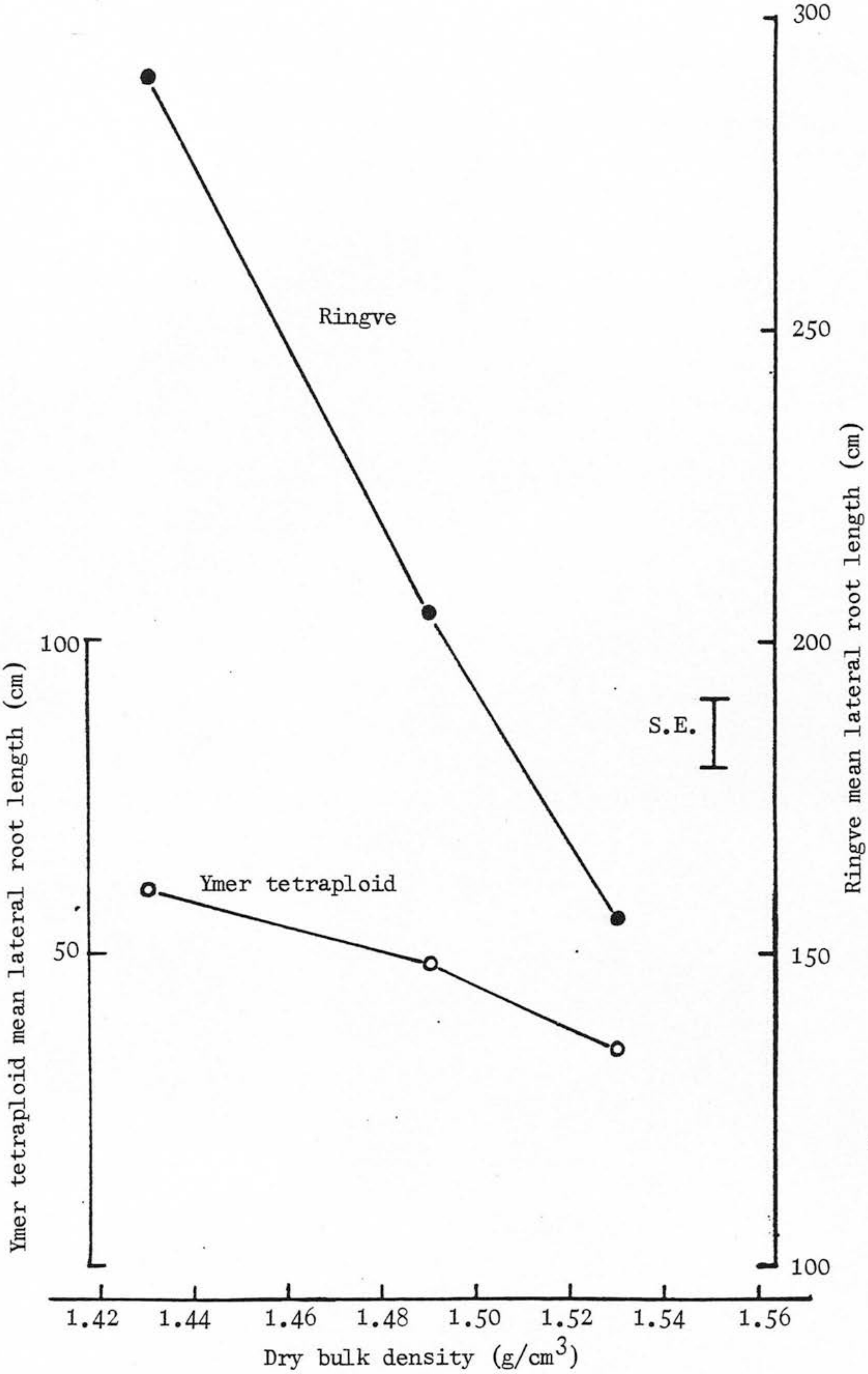



Figure 7.5 Effect of soil bulk density on lateral root length of the barley varieties Ymer tetraploid and Ringve.

### 7.3.3 Response of the Barley Varieties Varunda and Sumiremochi to Soil Compaction

#### 7.3.3.1 Seminal Root Growth (Table 7.10)

As expected Varunda had more seminal roots than Sumiremochi. In both varieties seminal root number did not change with soil compaction. There were varietal differences in seminal root length and diameter and the seminal root length of both varieties was decreased by increasing compaction. In common with other varieties studied in these experiments the seminal root diameter of Varunda increased with increasing compaction, however Sumiremochi did not show this response.

#### 7.3.3.2 Lateral Root Growth (Table 7.11)

Varietal differences in lateral root length were not paralleled by statistically significant varietal differences in root diameter. In both varieties root length decreased and root diameter increased as compaction increased.

#### 7.3.3.3 Dry Matter Production (Table 7.12)

There were significant varietal differences in dry matter production and in shoot/root ratio. There were no significant effects of soil compaction, although the shoot/root ratio of Sumerimochi was markedly greater with increasing soil compaction.

#### 7.3.3.4 Leaf Length and Area (Table 7.13)

Although first leaf length showed a statistically significant response to compaction this result seems to have been possibly due to an unusually vigorous Sumiremochi seedling giving an inflated value to the mean first leaf length at 1.44 $g/cm^3$ soil bulk density.

TABLE 7.10 RESPONSE OF THE BARLEY VARIETIES VARUNDA AND SUMIREMOCHI TO SOIL COMPACTION

Seminal Root Growth

| Soil compaction (Dry bulk density $g/cm^3$) | | Root number | | Root length (cm) | | Root diameter (mm) | |
|---|---|---|---|---|---|---|---|
| | | Varunda | Sumire-mochi | Varunda | Sumire-mochi | Varunda | Sumire-mochi |
| 1.40 | | 8.17 | 5.48 | 66.4 | 47.4 | 0.50 | 0.39 |
| 1.44 | | 7.33 | 5.67 | 55.6 | 50.2 | 0.53 | 0.43 |
| 1.47 | | 8.67 | 4.83 | 53.6 | 36.3 | 0.54 | 0.38 |
| Statistical significance | C | ns | | ** | | ns | |
| | V | *** | | *** | | *** | |
| | CxV | ns | | ns | | ns | |
| SED | C | 0.489 | | 3.23 | | 0.012 | |
| | V | 0.399 | | 2.64 | | 0.010 | |
| | CxV | 0.691 | | 4.57 | | 0.017 | |

TABLE 7.11 RESPONSE OF THE BARLEY VARIETIES VARUNDA AND SUMIREMOCHI TO SOIL COMPACTION

Lateral Root Growth

| Soil compaction (Dry bulk density $g/cm^3$) | | Root length (cm) | | Root diameter (cm) | |
|---|---|---|---|---|---|
| | | Varunda | Sumiremochi | Varunda | Sumiremochi |
| 1.40 | | 187.3 | 80.6 | 0.19 | 0.19 |
| 1.44 | | 137.0 | 79.6 | 0.21 | 0.21 |
| 1.47 | | 129.0 | 61.8 | 0.24 | 0.21 |
| Statistical significance | C | ns | | ** | |
| | V | *** | | ns | |
| | CxV | ns | | ns | |
| SED | C | 20.90 | | 0.009 | |
| | V | 17.06 | | 0.007 | |
| | CxV | 29.55 | | 0.012 | |

TABLE 7.12(A) RESPONSE OF THE BARLEY VARIETIES VARUNDA AND SUMIREMOCHI TO SOIL COMPACTION

Dry Matter Production

| Soil compaction (Dry bulk density $g/cm^3$) | | Total plant dry weight (g) | | Shoot/root ratio | |
|---|---|---|---|---|---|
| | | Varunda | Sumiremochi | Varunda | Sumiremochi |
| 1.40 | | 0.0447 | 0.0272 | 5.04 | 6.28 |
| 1.44 | | 0.0403 | 0.0320 | 5.81 | 6.86 |
| 1.47 | | 0.0398 | 0.0267 | 5.58 | 7.99 |
| Statistical significance | C | ns | | ns | |
| | V | *** | | ** | |
| | CxV | ns | | ns | |
| SED | C | 0.00326 | | 0.617 | |
| | V | 0.00266 | | 0.504 | |
| | CxV | 0.00461 | | 0.873 | |

TABLE 7.12(B) RESPONSE OF THE BARLEY VARIETIES VARUNDA AND SUMERIMOCHI TO SOIL COMPACTION

Dry Matter Production

| Soil Compaction (Dry Bulk Density $g/cm^3$) | | Shoot Dry Weight (g) | | Seminal Root Dry Weight (g) | | Lateral Root Dry Weight (g) | |
|---|---|---|---|---|---|---|---|
| | | Varunda | Sumire-mochi | Varunda | Sumire-mochi | Varunda | Sumire-mochi |
| 1.40 | | 0.037 | 0.023 | 0.0049 | 0.0026 | 0.0027 | 0.0014 |
| 1.44 | | 0.034 | 0.030 | 0.0046 | 0.0029 | 0.0018 | 0.0014 |
| 1.47 | | 0.034 | 0.024 | 0.0043 | 0.0020 | 0.0020 | 0.0010 |
| Statistical significance | C | ns | | ns | | ns | |
| | V | *** | | *** | | ** | |
| | CxV | ns | | ns | | ns | |
| SED | C | 0.0027 | | 0.00045 | | 0.00039 | |
| | V | 0.0022 | | 0.00037 | | 0.00032 | |
| | CxV | 0.0038 | | 0.00063 | | 0.00055 | |

TABLE 7.13 RESPONSE OF THE BARLEY VARIETIES VARUNDA AND SUMIREMOCHI TO SOIL COMPACTION

Leaf Length and Area

| Soil Compaction (Dry Bulk Density $g/cm^3$) | | Length 1st Leaf (cm) | | Length 2nd Leaf (cm) | | Leaf Area ($cm^2$) | |
|---|---|---|---|---|---|---|---|
| | | Varunda | Sumire-mochi | Varunda | Sumire-mochi | Varunda | Sumire-mochi |
| 1.40 | | 14 | 15 | 19 | 12 | 16 | 11 |
| 1.44 | | 14 | 17 | 17 | 12 | 15 | 13 |
| 1.47 | | 14 | 15 | 17 | 12 | 14 | 11 |
| Statistical significance | C | * | | ns | | ns | |
| | V | *** | | *** | | ** | |
| | CxV | ns | | ns | | ns | |
| SED | C | 0.5 | | 1.1 | | 1.3 | |
| | V | 0.4 | | 0.9 | | 1.0 | |
| | CxV | 0.7 | | 1.5 | | 1.8 | |

## 7.4 Discussion

In this section the response of barley seedlings to soil compaction is reviewed and the possible consequences of the responses to soil compaction for subsequent growth are discussed. The response of different barley varieties to soil compaction is also examined.

### 7.4.1 The Response of Barley Seedlings to Soil Compaction

As the environmental conditions under which the experiments were made could have differed between trials no direct comparison could be made of the growth of varieties included in different trials. However where the general response of the varieties to the soil compaction treatment were similar the results of different experiments have been drawn together for comparison of trends, not of absolute values. In reviewing the effects of soil compaction on seedling growth, attention is drawn in particular to the results of the first experiment, as the inclusion of six compaction levels allows the overall form of the plant growth response to soil compaction to be seen more clearly. In the other two experiments, because there were only 3 compaction levels, any atypical mean value made the form of plant growth response to soil compaction more difficult to identify. In a compacted soil increased bulk density is accompanied by decreased porosity, due in particular to a reduction in the proportion of large pores, and by an increase in soil strength (see Section 5). These changes in soil physical conditions may affect plant growth directly, or may act indirectly through their effect on soil chemical conditions.

It has been found that roots are unable to decrease their diameters to penetrate rigid pores (Wiersum 1957, Goss 1977). Therefore a root growing through soil must either pass through pores larger than its own diameter or enlarge pores initially narrower than its diameter. To enlarge pores the root tip displaces soil particles and there is thus a reaction from the soil which exerts a force on the root. The magnitude of the force exerted by the soil depends on its compressibility. In a compact soil with a reduced proportion of pores large enough to accommodate roots and with increased soil strength, there is thus an increased resistance to root penetration and root growth is impeded. It has generally been found that the rate of root elongation is inversely proportional to soil bulk density and soil strength (see Section 5). The reduction in root length caused by mechanical impedance is usually accompanied by an increase in root diameter. Barley (1968) suggested the increased diameter of the root may facilitate penetration of compact soil as radial enlargement of the root may lead to tensile rupture of the soil ahead of the root tip and so reduce the soils resistance to penetration. Abdalla, Hettiaratchi and Reece (1969) made a theoretical analysis of the mechanics of root growth and concluded that soil resistance to root elongation could be reduced by an increase in the diameter of the sub-apical root zone.

In the present investigation the barley seedling root system response to increased soil compaction followed the pattern outlined above; root length decreased and root diameter increased as soil bulk density increased. The dissection of the root systems into main axes and laterals gave an opportunity to study the change in the developmental pattern of the root system when subjected to soil compaction. It was found that although both seminal and lateral root length decreased with increasing soil bulk density the decrease in lateral root length was usually proportionally greater; the ratio of lateral to seminal root weights showed a similar response (Table 7.14).

TABLE 7.14 THE RESPONSE OF BARLEY VARIETIES TO SOIL COMPACTION

The relationship of seminal and lateral root growth

EXPERIMENT 1: Barley Variety Georgie

| Soil Compaction (Dry bulk density $g/cm^3$) | Ratio Lateral to Seminal Root Length | Ratio Lateral to Seminal Root Weight |
|---|---|---|
| 1.43 | 4.97 | 1.6 |
| 1.47 | 5.18 | 1.35 |
| 1.48 | 4.72 | 1.40 |
| 1.51 | 4.00 | 0.95 |
| 1.52 | 3.68 | 0.90 |
| 1.56 | 4.02 | 1.11 |

EXPERIMENT 2: Barley Varieties Ringve and Ymer tetraploid

| Variety | Soil Compaction (Dry bulk density $g/cm^3$) | Ratio Lateral to Seminal Root Length | Ratio Lateral to Seminal Root Weight |
|---|---|---|---|
| Ringve | 1.43 | 4.39 | 0.61 |
| | 1.49 | 4.02 | 0.67 |
| | 1.53 | 2.71 | 0.52 |
| Ymer tetraploid | 1.43 | 1.11 | 0.22 |
| | 1.49 | 1.10 | 0.24 |
| | 1.53 | 0.94 | 0.20 |

EXPERIMENT 3: Barley Varieties Varunda and Sumiremochi

| Variety | Soil Compaction (Dry bulk density $g/cm^3$) | Ratio Lateral to Seminal Root Length | Ratio Lateral to Seminal Root Weight |
|---|---|---|---|
| Varunda | 1.40 | 2.82 | 0.55 |
| | 1.44 | 2.46 | 0.39 |
| | 1.47 | 2.41 | 0.47 |
| Sumiremochi | 1.40 | 1.70 | 0.54 |
| | 1.44 | 1.59 | 0.48 |
| | 1.47 | 1.70 | 0.50 |

These latter observations contrast with those of Goss and Russell (1980) who, after a study of the effects of mechanical impedance on the root growth of barley, reported that the proportional reduction in the length of lateral roots is similar to that of seminal roots when they are exposed to the same external pressure. Goss and Russell (1980) in a modification of a technique previously used by several other workers (Gill and Miller 1956, Barley 1963, Abdalla, Hettiaratchi and Reece 1969) grew plants in containers filled with small glass spheres (ballotini) to which various external pressures could be applied. The use of these artificial systems has been advocated because mechanical impedance can be varied while all other factors which may affect root growth are kept constant. The growth of plants in artificial systems can facilitate the interpretation of root growth responses to mechanical impedance. However it seems from a comparison of the results presented in this thesis with those of Goss and Russell (1980) that there may be certain qualitative differences in the developmental pattern of mechanically impeded barley root systems depending on the growth medium in which they are subjected to mechanical stress i.e. soil or ballotini. These findings indicate that it may be unwise to use results gained in ballotini systems to predict the effects of mechanical impedance on soil grown root systems.

So far discussion has centred on the effects of soil compaction on soil physical conditions and the consequent effects on root growth. However compaction may also affect soil chemical conditions, particularly aeration. It has frequently been found that the increased bulk density of compact soils is particularly associated with a reduction in the frequency of large soil pores (> 30 μm diameter) from which water can drain freely under gravity (Russell 1977). Thus compaction, by reducing the proportion of these drainable soil pores, may restrict aeration as transfer of gases between soil and atmosphere occurs largely in air filled pores because oxygen diffuses ten thousand times more rapidly in air than in water (Russell 1977). However there appears to be no constant relationship between the air-filled pore space and the extent to which anaerobic conditions can develop (Grable 1966), although obviously the lower the air-filled pore space the greater the probability that anaerobic conditions will develop.

In the present experiments soil porosity was reduced from 0.47≠ at the lowest compaction level to 0.41≠ at the highest compaction level. Unfortunately it was not possible to take soil samples from the pots of compact soil to determine their soil water content and air filled porosity as this would have led to the loss of an unknown quantity of seedling roots. However, assuming soil moisture contents of 20% or 25% w/w+, the air filled porosity of soil compacted to 1.56 $g/cm^3$ dry bulk density would have been 10% or 2% v/v respectively, whereas in soil compacted to 1.40 $g/cm^3$ the air filled porosity would have been 20% or 12% v/v respectively. On the basis of this analysis it would appear that anaerobic conditions could have developed in soil compacted to the higher bulk densities used in these experiments.

Poor aeration can have similar effects on root growth to those of mechanical impedance i.e. a reduction in root elongation coupled with an increase in root diameter (Eavis and Payne 1969). Thus it may be difficult to differentiate between the effects of aeration and mechanical impedance when studying the response of roots to increasing soil compaction. Eavis and Payne (1969) found that although mechanical impedance and poor aeration had similar effects on the morphology of pea roots, root weight was reduced by low oxygen concentrations but not by increased mechanical impedance. In the present

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≠ $\text{Porosity} = (p_s - p_b)/p_s$

where $p_b$ represents the dry bulk density of the soil and $p_s$ represents soil particle density which may be taken as being 2.65 $g/cm^3$ (Marshall and Holmes 1979).

+A similar soil of the Macmerry Soil Series at -0.05 bars soil moisture tension had a soil moisture content of 30% w/w (Dr D Campbell, Scottish Institute of Agricultural Engineering, personal communication 1981).

experiments root weight either increased or was unaffected by increasing soil compaction. Also Eavis and Payne (1969) found that the effects of increased soil compaction and poor aeration were additive and where both of these factors were operative root extension was reduced to a greater degree than was predicted from the inverse linear relationship of soil bulk density and root length. In the first experiment lateral root length showed an inverse linear relationship with increasing soil bulk density, although at the highest soil compaction level lateral root length was greater than was predicted by this relationship. Thus although there is no clear evidence that poor aeration was inhibiting root growth in these experiments, the possibility cannot be completely excluded. In the first experiment it was observed that roots grew largely near the soil surface at the highest compaction level and this could have been due to anaerobic conditions developing in the compact soil deeper in the pot causing root growth to be restricted to the better aerated soil near the surface.

The most marked effect of increasing soil compaction was to change the pattern of dry matter distribution between shoots and roots. In the first experiment there was a pronounced linear decrease in shoot/root ratio as compaction increased (Figure 7.4). The decrease in shoot/root ratio was associated with both a decrease in shoot dry weight and an increase in root dry weight (Table 7.4, Figure 7.3). Root dry weight increased despite an overall reduction in root length because root weight per unit length increased as soil compaction increased (Table 7.15). As root length decreased root diameter increased and it was at first thought that the increase in root weight per unit length was due to the resultant change in root volume per unit length. However after further analysis it was found that root weight per unit volume also increased as soil compaction increased (Table 7.15).

TABLE 7.15 RESPONSE OF BARLEY SEEDLINGS TO SOIL COMPACTION
Root weight per unit length and volume

| Soil Compaction (Dry bulk density $g/cm^3$) | Root weight per unit length ($g \times 10^{-5}/cm$) | | Root weight per unit volume ($g \times 10^{-2}/cm$) | |
|---|---|---|---|---|
| | Seminals | Laterals | Seminals | Laterals |
| 1.43 | 9.07 | 2.94 | 8.5 | 16.3 |
| 1.47 | 12.22 | 3.18 | 10.7 | 14.8 |
| 1.48 | 13.52 | 4.00 | 11.0 | 16.0 |
| 1.51 | 16.96 | 4.02 | 13.3 | 16.1 |
| 1.52 | 18.61 | 4.53 | 13.9 | 17.5 |
| 1.56 | 19.67 | 5.41 | 12.9 | 17.1 |

Wilson, Robards and Goss (1977) reported that the increase in diameter of barley roots subjected to mechanical impedance in ballotini experiments was associated with an increase in the thickness of the cortex and in the number of cortical cells seen in a transverse section of root. No observations were made of the anatomy of roots subjected to mechanical impedance in the present experiments. However the increase in root weight per unit volume indicates an increased incorporation of structural material per unit root volume which may have been associated with changes in root anatomy similar to those observed by Wilson, Robards and Goss (1977).

A number of workers have measured root weight and then estimated root length from a regression of root weight against root length (e.g. Gregory, McGowan, Biscoe and Hunter 1978). The results from the present experiments can be used to illustrate two criticisms of this procedure.

1. Root axes are heavier than lateral roots per unit root length and thus a given weight of lateral root is much longer than a given weight of seminal root. Any change in the proportion of seminal to lateral root length may thus change the relationship of root length to root weight.

2. Root weight per unit length may be affected by mechanical impedance. Soil strength can be modified by changes in soil moisture content as well as changes in soil bulk density (Taylor and Gardner 1963). Thus the relationship of root weight to root length may be altered by changes in soil moisture content or soil bulk density.

Thus unless the above mentioned factors can be taken into account it would seem unwise to estimate root length from root weight data.

In the first experiment the increase in root weight, as soil compaction increased, was balanced by a decrease in shoot weight. The decrease in shoot weight was accompanied by a noticeable, though not significant, decrease in leaf area but not leaf length (see Table 7.5). Similar changes in dry matter distribution were also found in the second experiment. The shoot dry weight and leaf area of both Ringve and Ymer tetraploid decreased as soil compaction increased and this was coupled with a significant decrease in the length of the second leaf.

Thus increasing soil compaction can, in addition to impeding root extension, change the balance of dry matter accumulation in favour of the root system to the detriment of shoot growth up to 14 days after planting. This effect may be transient.

The source of the assimilates used in dry matter production changes during the first two weeks of seedling growth, i.e. the duration of an experiment. In barley seedlings (cv. Proctor) it has been found that growth up to 8 days after imbibition is dependent upon the redistribution of seed reserves. As these reserves are exhausted growth becomes increasingly dependent on photosynthates produced by the first leaf. The second leaf begins to expand after 10 days and may be contributing to growth by 14 days (Dale and Felippe 1972). If it is assumed that the developmental patterns of Proctor, Ymer tetraploid and Ringve are broadly similar it may be deduced that the reduction in the growth of the second leaf with increasing soil compaction may have been due to a reduction in its supply of assimilate due to an increase in the proportion of the photosynthates produced by the first leaf being used in root growth. This indicates that soil compaction was continuing to influence dry matter partitioning two weeks after planting, and therefore suggests that soil compaction may have longer term effects on the pattern of crop growth (see Section 7.4.2).

It is not known how plants control the partitioning of dry matter between shoot and root, although it is thought that several mechanisms may be involved (Troughton 1977). Growth has frequently been considered in terms of the relationships between 'sources' where metabolites are synthesised or nutrients absorbed and 'sinks' where they used to create new tissues. Although plant roots are the source of mineral nutrients required by the shoot they must also act as a 'sink' for nutrients to meet their own growth requirements. Observations of the changes in shoot/root ratio caused by varying environmental conditions led to the proposal of the nearest sink hypothesis which suggests that when the size of a 'source' is reduced the organs most remote from it are most affected (Troughton 1974). In the present study the reduction in root length in compact soil may have meant that the root system was less able to absorb nutrients such as potassium and phosphate which diffuse very slowly through the soil and usually travel only a few millimetres to root surfaces (Cannell and Drew 1973). Applying the nearest sink hypothesis it can be seen that as the root system was nearest to the 'source' of nutrients it would have been able to compete more effectively than the shoot for a share of the limited nutrient supply. The consequent reduction in the supply of minerals to the shoot may have reduced the ability of the shoot to incorporate photosynthates produced by the leaves, the excess being accumulated as dry matter in the roots.

It is possible that the changes in the levels of plant growth regulators that are thought to occur during the roots response to mechanical impedance may affect dry matter partitioning. The growth of an organ may be determined by its competitive ability as a sink and there is considerable evidence that plant growth regulators play an important role in regulating the metabolic demands (sink strengths) of various organs within the plant (Wareing 1979).

Barley (1976) suggested that the response of roots to mechanical impedance may be mediated by growth regulators, particularly ethylene, and a number of studies have produced evidence to support this hypothesis. Wilson, Robards and Goss (1977) reported that mechanical impedance reduced the length and increased the cross-sectional area of the cortical cells of barley roots; similar changes in cell dimensions can be induced by treatment with ethylene and auxin (Osborne 1976). More direct evidence was produced by Kays, Nicklows and Simons (1974) who found a temporary increase in ethylene evolution when the extension of pea roots was impeded. Wilkins, Alejar and Wilkins (1978) reported that the incorporation of 3,5-diiodo-4-hydroxybenzoic acid (DIHB) into compact soil improved the growth of barley plants relative to that in untreated compact soil. They suggested that DIHB may act by alleviating 'ethylene type' growth reactions and this view was supported by their observation that DIHB significantly reduced the growth inhibiting effects of high concentrations of ethylene supplied exogenously to barley seedlings. Although the evidence is largely circumstantial it seems that ethylene and perhaps other plant growth regulators play a part in controlling plant responses to compact soil conditions.

7.4.2 Possible Effects of Soil Compaction on Crop Growth

It is evident from the previous section that soil compaction could affect shoot growth either by:-

1. Reducing overall root length and restricting the volume of soil explored by roots and thereby reducing the root systems ability to exploit the soil reserves of phosphorus and potassium+, an adequate supply of which are essential for shoot growth. The rate of dry matter production by crops

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+The principal factors affecting the supply of nutrient to a plant are the total quantity of diffusible material, the rate at which the nutrient can move, and the distance it has to travel to the root surface. The diffusion coefficients of potassium and phosphate are often very low and mass flow contributes little to their supply (Baldwin 1975); thus the adequate exploitation of the soil reserves of these nutrients requires a well developed root system.

is frequently a function of the supply of mineral nutrients (Milthorpe and Moorby 1979).

2. Affecting either the production of growth regulators by the root or their transport from root to shoot; the poor shoot growth found in plants subjected to adverse soil conditions is frequently associated with a reduction in the transport of the plant growth regulator cytokinin from root to shoot (Skene 1975).

In reducing root elongation soil compaction may also reduce the ability of plants to endure adverse soil conditions. For example the development of roots to a sufficient depth such that an adequate and continuing supply of water is assured could be a major requirement for the survival of seedlings if the surface soil dries out.

In the present experiments the effects of soil compaction on shoot growth were small. However the trials ran for a very short period and it is possible that the effects on shoot growth were just beginning to be manifest. In field trials it has been found that although the emergence of direct drilled crops may be good their subsequent growth is poor (Dr. J.C. Holmes, personal communication 1981). The reduction in leaf area with increasing compaction could, if it involved a decrease in photosynthate production, limit the potential yield. Dale, Felippe and Fletcher (1972) investigated the importance of the photosynthetic activity of the first leaves of barley (cv. Proctor) in determining grain yield. They found that if the first or second leaves were shaded there was a reduction in grain yield which was mainly due to the production of fewer tillers by shaded plants. They suggested that the photosynthetic activities of the first leaves could influence plant development and therefore yield potential because they are the main photosynthetic organs during the time mainstem and tiller apices are developing rapidly and undergoing the transition from the vegetative to the floral state.

### 7.4.3 The Response of Barley Varieties with Contrasting Root Characteristics to Soil Compaction

Although genotype/environment interactions have been found with respect to the ability of plant roots of different species to penetrate compact soil (see Section 5) the results of the present study give little direct evidence of such interactions in the response of barley varieties to soil compaction. However there were marked varietal differences in the growth of root systems in compact soil which may determine the effect of such soil conditions on the yield bearing potential of different varieties. It has been shown that in favourable conditions the plant root system may be considerably larger than the minimum size needed for the provision of adequate supplies of water, nutrients and growth substances to shoots (Russell 1977). However the shorter root length of plants growing in compact soil may be unable to meet all the plants requirements for mineral nutrients with consequent effects on plant growth (see Section 7.4.2).

Soil compaction had similar effects on the root elongation of all varieties. However in the variety comparisons certain varieties had more vigorous root systems so that even at the highest soil compaction levels they produced a considerably greater root length than the varieties with which they were compared. In the second experiment Ringve produced three times the length of root produced by Ymer tetraploid (see Tables 7.6 and 7.7). In the third experiment the varietal difference was smaller although at the end of the experiment the root system of Varunda was almost twice as long as that of Sumiremochi.

It seems possible that the varieties with more vigorous root systems and thus relatively greater root length, even in compact soil, would be better able to meet the plants requirements for nutrients. Therefore although the early growth of varieties with vigorous root systems may be somewhat reduced by compaction the reduction in growth may be less than that experienced by varieties with relatively slow growing root systems. Furthermore varieties with relatively large root systems may be better able to endure other adverse soil conditions in addition to soil compaction (see Section 7.4.2).

The varieties used in the second and third compaction experiments were selected for their contrasting root characteristics (see Section 6). Comparing the measures of seminal root characteristics made in the compaction experiments (Tables 7.6 and 7.10) and in the seedling root growth surveys (Section 6, Tables 6.2 and 6.5), it can be seen that root diameter and root number were similar in all trials, thus confirming that root diameter and root number are heritable characters.

In Section 7.1 it was suggested that thicker roots may be able to penetrate compact soil more easily. However the results of the second experiment gave no evidence to support this. In experiment three the growth of two varieties with differing numbers of seminal roots were compared, because it was thought that a variety with many seminal roots may be better able to become established in compact soil; again the results did not support this suggestion.

However it may be suggested that the result discussed above would not have been found if plants had been grown in conditions more closely approximating to those found in the field. The artificially compacted soil produced for the experiments was, within the limits of this technique, reasonably uniform with no cracks. Although the use of artificially compacted soil minimises experimental variation and enables the response to compaction to be accurately characterised, it has the disadvantage that the soil so compacted lacks the cracks and continuous pores characteristic of many soils compacted under a direct drilling system (see Section 1). In compact field soils it has frequently been found that roots tend to grow through cracks and channels which offer less resistance to penetration than the structural units from which the soil is composed (Russell 1977). Thus in a field soil a variety producing many seminal roots would have a greater chance of one or more roots encountering cracks or channels along which roots can grow and profilerate to sufficient length to meet the needs of the developing plant.

The present experiments using artificially compacted soil gave no evidence that certain seminal root characteristics could affect the ability of a variety to grow in compact soil. However from the preceding discussion it may be suggested that in field conditions varieties producing many seminal roots or with vigorous root systems may be more successful in compact soil. Further work is needed to test this hypothesis.

# SECTION 8

# CONCLUSIONS

## 8. CONCLUSIONS

In some field experiments there was evidence that varieties differed in their suitability for use in a direct drilling system. However the results were too inconsistent to identify factors which made a variety adapted to compact soil conditions. It was concluded from the literature that increased soil compaction was one of the main factors limiting crop growth under direct drilling and thus varieties with root systems adapted to compact soil would be more suitable for use with direct drilling.

Laboratory studies demonstrated wide-ranging phenotypic variation in barley seedling root systems. Several root characters, particularly root number and length, were highly heritable and the results indicated that these characters were controlled by additive polygenic systems which would facilitate selection for these root characters in plant breeding programmes.

Differences in seminal root number and diameter of barley varieties did not affect their response to soil compaction in pot experiments. However it was suggested that in field conditions varieties with more vigorous root systems or prodicing many seminal roots would be better able to grow in compact soil.

# SECTION 9

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# APPENDIX I

BRITISH STANDARD 1377 : 1967
Methods of Testing Soils for Civil Engineering Purposes
Soil Compaction Tests

4.1 Test 11. Determination of the Dry Density/Moisture Content Relation - 5.5 lb (2.5 kg) Rammer Method.

4.1.1 Scope

The test covers the determination of the weights of dry soil per cubic foot when the soil is compacted in a specified manner over a range of moisture contents including that giving the maximum weight of dry soil per cubic foot. In this test a 5.5 lb (2.5 kg) rammer falling through a height of 12 in. (30.5 cm) is used.

4.1.2 Apparatus

(1) A cylindrical metal mould having an internal diameter of 4 in. (10.2 cm), an internal effective height of 4.584 in. (11.6 cm) and a volume of $^1/30$ $ft^3$ (994 $cm^3$). Mould fitted with a detachable baseplate and a removable extension approximately 2 in. (5.1 cm) high.

(2) A metal rammer having a 2 in. (5.1 cm) diameter circular face, weighing 5.5 lb (2.5 kg). Rammer drops 12 in. (30.5 cm). It is essential that the design of machine is such that the mould rests on a heavy solid base.

(3) Balance readable and accurate to 1 g.

(4) A palette knife (a good size = blade approx. 10 cm long and 2 cm wide).

(5) A straight edge e.g. a steel strip 30 cm x 2.5 cm x 3 mm thick with one bevelled edge.

(6) A $^3/4$ in. (20 mm) B.S. test sieve and a receiver.

(7) A large metal tray.

(8) Apparatus for moisture content determination.

4.1.3 Procedure

4.1.3.1 Soil not susceptible to crushing during compaction.

(1) 5 kg sample of air-dried soil passing $^3/4$ in. (20 mm) B.S. test sieve. Sample shall be mixed thoroughly with a suitable amount of water depending on the soil type (Notes 1 and 2).

(2) Mould with base-plate attached, shall be weighed to the nearest 1 g ($W_1$). The mould shall be placed on a solid base e.g. a concrete floor or plinth attached to floor. Soil compacted into mould with extension attached, in 3 layers of approximately equal weight, each layer being given 25 blows from the rammer dropped from a height of 12 in. Blows uniformly distributed over the surface of each layer.

The amount of soil used shall be sufficient to fill the mould, leaving not more than about $^1/4$ in. (6 mm) to be struck off. Extension then removed and compacted soil carefully levelled off top of mould using straight edge.

(3) Weigh mould, base plate and wet soil ($W_2$). Take representative sample of soil and determine moisture content (m).

(4) Remainder of sample rubbed through $^3/4$ in. (20 mm) sieve and mixed with remainder of original sample. Suitable increments of water successively added and mixed into sample and above procedure (2) to (4) repeated. At least 5 determinations should be made and the range of moisture contents should be such that the optimum moisture content at which the maximum dry density occurs, is within that range.

4.1.4 Calculations

(1) Weight of wet compacted soil per cubic foot (bulk density ($\gamma$)) of each compacted specimen shall be calculated from the formula

$$\gamma = \frac{W_2 - W_1}{15.12}\ (\mathrm{lb/ft^3})$$

$W_1$ = weight of mould and base (g)

$W_2$ = weight of mould, base and soil (g)

(2) Weight of dry soil per cubic foot (dry density ($\gamma d$)) shall be calculated from the formula

$$\gamma d = \frac{100\gamma}{100 + m}\ (\mathrm{lb/ft^3})$$

Where m = moisture content of soil (percentage w/w)

(3) Dry densities ($\gamma d$) obtained in a series of determinations plotted against moisture contents (m). Draw smooth curve through the resulting points and the position of the maximum on this curve shall be determined.

NOTES

(1) The amount of water to be mixed with the air-dried soil at the commencement of the test will vary with the soil under test. In general with sandy and gravelly soils a moisture content of 4% to 6% would be suitable, with cohesive soils a moisture content about 8% to 10% below the plastic limit of the soils would be suitable.

(2) It is important that the water be thoroughly mixed with soil as inadequate mixing gives rise to variable test results. Particularly important with cohesive soils when adding a substantial quantity of water to the air-dried soil.

$\neq$15.12 is replaced by 943.50 to give density in g/cm$^3$.